STREET RAILWAY MOTORS.

STREET RAILWAY MOTORS:

WITH

DESCRIPTIONS AND COST OF PLANTS AND OPERATION OF THE VARIOUS SYSTEMS IN USE

OR PROPOSED FOR

MOTIVE POWER ON STREET RAILWAYS.

BY

HERMAN HAUPT, C. E.

CHIEF OF BUREAU OF MILITARY RAILROADS DURING THE LATE WAR; LATE CHIEF ENGINEER PENNSYLVANIA R. R.; GENERAL MANAGER NORTHERN PACIFIC R. R.; PIEDMONT AIR LINE; CHIEF ENGINEER TIDE WATER PIPE LINE.

PHILADELPHIA:
HENRY CAREY BAIRD & CO.
INDUSTRIAL PUBLISHERS, BOOKSELLERS AND IMPORTERS,
810 WALNUT STREET.
LONDON: E. & F. N. SPON,
125 STRAND.
1893.

PRINTED AT THE COLLINS PRINTING HOUSE,
705 Jayne Street,
PHILADELPHIA, U. S. A.

PREFACE.

THE present age seems to be peculiarly prolific in the invention of motors for street railways and in new applications of old and recognized motor forces for propulsion of the cars used for urban and suburban transit. Some of these possess decided merits, and present claims for the support of capitalists and of the public that are, at least, worthy of careful examination; others are advanced by parties who are evidently ignorant of the thermo-dynamic, chemical, and mechanical laws upon which some of these operations depend, and schemes are sometimes presented that are visionary and impracticable. A brief review of the plans proposed for street railways, their merits and defects, with the cost of plant and of operation, will probably possess sufficient interest at the present time to excuse the preparation and publication of this volume.

The aim of the writer has not been to furnish an elaborate treatise requiring for its comprehension a high degree of technical knowledge, but rather a simple statement of principles and their applications that will be

readily comprehended by persons of limited scientific attainments—a treatise for the use and information of investors and of the public.

The subjects here considered are horse railroads, steam motors, cable traction, electric roads, compressed-air motors, ammonia motors, hot-water motors, gas motors, and carbonic-acid motors.

It is not proposed to attempt any details of mechanical construction or furnish illustrations. This ground has been fully covered by several volumes already published. The object is simply to give results, with such simple explanations of principles as will be of interest and be intelligible to practical men who may be called upon to contribute capital for construction or use their votes or influence in favor of any proposed system of rapid or local transit in cities.

PHILADELPHIA, March 25, 1893.

ADDRESS.

As frequent inquiries are made for the address of the author, it may be well to state that his permanent summer residence is at St. Paul, Minn.

Communications may be addressed as follows:

H. HAUPT, 593 Holly Avenue,
St. Paul, Minn.

or care of L. M. HAUPT, 107 N. 35th St.,
Philadelphia, Pa.

CONTENTS.

I. Horse Railways.

III. Ammonia Motor.

IV. The Hot-water Motor.

V. Gas Motors.

VI. The Pneumatic or Compressed Air Motor.

VII. TESTS OF THE HARDIE COMPRESSED AIR MOTOR.

VIII. Economical Modes of Compression.

IX. Cost of Operation of the Compressed Air Motor for One Day—Six Miles Double Track.

X. Other Air Motors.

XI. Cable and Electric Roads.

XII. Electric Lines.

XIII. Low-pressure Air Motors.

XIV. Storage Batteries.

XV. Cost of Carbonic Acid as a Motive Power.

XVI. Transmission of Power by Means of Pipes.

XVII. General Summary.

APPENDIX.

STREET RAILWAY MOTORS.

I.

HORSE RAILWAYS.

HORSE RAILWAYS, as also all other railways operated by independent motors, require merely a surface track, the cost of which may vary from $5000 to $40,000 per mile of single track; $5000 supposes a light 45-pound rail laid on cross-ties, very light grading, and no paving. Such a track might suit for a suburban extension of a city line in a sparsely-settled district. A more safe general average of cost will be taken at $10,000 per mile as a standard for comparison of cost of plant and operation for the various systems to be considered.

It will be understood, as a matter of course, that before commencing construction a competent engineer should be employed to prepare plans, profiles, and estimates upon which the financial arrangements must be based; but $10,000 may be taken as a fair average for surface roads, and will answer as a basis for comparison of cost of plant in the systems under consideration.

COST OF PLANT.

One of the reports of the Second Avenue Railroad, of New York, gave number of cars 167, number of

horses 1197, cost of cars $92,800, average cost of one car $556. The interest paid on car-shed and stable property was $24,150, representing a capital of $402,500. The length of road operated 8 miles of double track; number of horses to one car 10.

With these data the cost of plant may be approximately estimated on the Second Avenue Railroad:—

16 miles single track, $10,000	$160,000
167 cars	92,800
1197 horses, $150	179,550
Real estate, car-sheds, and stables	402,500
Harness, furniture, and incidentals	50,000
Cost of plant for 8 miles, based on cost of Second Avenue Railroad, of New York	$884,850

It was stated that the average cost per car was only $556. This is below the average. A new 16-foot car costs from $750 to $1500 for the body alone, and trucks about $600. In estimating the cost of new plants, therefore, it will not be safe to allow less than $1000 per horse-car, to which the cost of horses must be added.

The number of cars was given in the report as 167, but it was stated that this number included many old and comparatively useless cars, and that the average number in daily use was about 105, or only 60 per cent. of the whole number.

Expenses of Operation.

Repairs of harness	$1,200
Horse-shoeing	16,593
Horses	42,000
Stable expenses	46,542
Feed	108,785
Interest and depreciation in horses, etc.	17,490
Interest, taxes, and insurance on stables	12,000
Cost of horse-power one year	$244,610

Allowing 72 miles as the average daily run, and 105 cars in average daily use, the annual car-miles would be 2,759,400, and the cost of horse-power per car-mile would be 9 cents, exclusive of conductors, drivers, car expenses, or track repairs.

The other expenses of operation were—

Repairs of cars	$29,000
Interest and depreciation of cars	9,200
Conductors and drivers	167,335
Interest and repairs of car-sheds (est.) . .	16,000
Total car expenses	$221,535

Track expenses:—

16 miles single track, $2932 per mile . . .	$46,912

The most satisfactory unit for comparison of expenses of different systems is the car-miles, and in the case under consideration, the car-miles being taken at 2,759,400, the results are:—

Cost of horse-power	9 cents.
Car expenses	8 "
Track repairs	1.68 "

The total expenses, including a dividend of $72,000, were $730,409, which would leave for general and incidental expenses a balance of $145,409, and the total expenses may be thus stated:—

Power alone . . .	$244,610, per car-mile	9 cents.
Cars and conductors .	221,535, " " "	8 "
Track repairs . . .	46,912, " " "	1.68 "
General and incidental expenses . . .	145,409, " " "	5.30 "
	$658,466	23.98 "

The total number of passengers carried on the Second Avenue Railroad for the year under consideration was

16,062,560, and the cost per passenger carried was 4.55 cents, which included the dividend of $72,000. Exclusive of dividend, the cost was 4.10 cents.

From the reports of 16 horse-car companies in the city of New York, operating 102 miles of road, with 1297 cars and 10,301 horses, it appears that the expenses for one year were :—

Repairs of harness . .	$41,861,	per horse	$4.06
Shoeing horses . . .	234,578,	" "	22.77
Feed	1,281,316,	" "	124.39
Stable expenses . .	434,014,	" "	42.13
Replacing horses . .	227,693,	" "	22.10
	$2,219,462		$215.45

Cost of one horse one month $18, number of horses to one car 8.

If the whole equipment were in daily use, running 72 miles per day for 365 days, the car mileage would amount to 34,075,000 miles, and the cost of horse-power per car-mile would be 6½ cents; but if the same proportion of cars were in daily use as on the Second Avenue Railroad, the car mileage would be 20,445,000, and the cost per car-mile 10.8 cents.

Charles H. Davis, C. E., gives some useful data in reference to street railways.

For 45 horse railroads in Massachusetts, from 1885 to 1890, the total average investment, real estate, road, and equipment, is given :—

Per mile of street	$33,406.00
" " of track	$31,093.00
Car-miles per annum per mile of street .	43,345
Passengers carried per annum per mile of street	251,816
Passengers carried per car-mile . .	5.81
Operating expenses " "	24.32 cents.
Interest at 6 per cent. on investments per car-mile	4.62 "
Total interest and operating expenses .	28.94 "
Cost per passenger carried, interest excluded	4.18 "
" " " " included	4.98 "

Conditions stated by C. H. Davis, in comparative estimates: Horse-cars, 72 miles per day, running 18 hours, 4 miles per hour. Depreciation of horses, 20 per cent.; of cars, 5 per cent. Track repairs and depreciation, 10 per cent. 3 men per car, $1.60 each. Value of car and horses, $1900. 6 horses per car. Keep, 35 cents per day.

In Rochester, the earnings of horse railways for June, 1891, were 14.37 cents per car-mile, and expenses 11.06 cents, as reported. Those of the West End Company of Boston for same time were: Earnings, 34.28 cents per car-mile; expenses, 24.03.

The number of rides per capita in cities of population from 20,000 to 30,000 is given as an average of 30, increasing regularly to 190 with increase of population to 800,000 or over.

A census bulletin issued by Superintendent Porter gives statistics of 30 roads operated by animal power with 552 miles of track. Total cost, with equipment, $22,788,277. Operating expenses, $6,986,019. Passengers carried, 190,434,783. Expenses per car-mile, 18.16 cents. Cost per passenger, 3.67 cents.

A report of earnings and expenses of the West End Company of Boston for April, May, and June, 1892, per car-mile for horse-cars, including motive power, car repairs, damages, wages, and other expenses, gives :—

	Cents.
Earnings per car-mile	34.28
Expenses " "	24.03
Net receipts	10.25

Another report of the West End Company for April, May, June, July, and August, 1891, gives for the horse railroad :—

	Cents.
Motive power per car-mile, average of 5 months	10.60
Car repairs " "	0.56
Damages " "	0.30
Conductors and drivers	8.22
Other expenses	4.77
Total expenses	24.50
Earnings	35.20
Net earnings per mile	10.71

Mr. H. H. Windsor, editor of *Street Railway Review*, of Chicago, in reply to a private letter, states that there is a difficulty in procuring reliable information in regard to statistics of horse railway companies, arising from the fact that there is no general, uniform system of accounts such as prevails amongst railroads; but that for the year 1890 he has his own figures, compiled while secretary of the Chicago City Railway, and which show all the expenses except interest and dividend, being 21.98 cents per car-mile for horse roads.

Since that time the cost of horse-power has increased, owing to increased cost of feed, and for the last year the total expenses have been 24 cents.

The most important datum, in comparison of cost of operation of the different systems, is the power required for propulsion; and its cost per car-mile, from the data furnished, would appear to be, with horses for the power alone, exclusive of conductors, drivers, or other expenses outside the stables, from 9 to 10 cents per car-mile.

The total expenses for horse service appear to be nearly uniform at about 24 cents per car-mile.

In a comparison of expenses of operation between horse-power and other motors, it will be convenient to ascertain the percentages which the several items bear to the whole motive-power expense.

	Per cent.
Repairs of harness	0.5
Horse-shoeing	7.0
New horses	17.0
Stable expenses	18.0
Feed	50.0
Interest, taxes, insurance, miscellaneous	7.5
	100.0

If the cost of horse-power per car-mile be taken at an average of 10 cents, then the cost of each of the above items will be:—

Repairs of harness	½ mill.
Horse-shoeing	7 mills.
New horses	1.7 cents.
Stable expenses	1.8 "
Feed	5.0 "
Other expenses	7½ mills.
	10 cents.

II.

STEAM MOTORS.

STEAM MOTORS for street railways are now but little used. Wherever tried they have in general been abandoned and some other mode of propulsion adopted. A brief consideration of steam motors, however, seems to be necessary as one of the steps in the transition to the present more popular systems, and as illustrating principles applicable to the use of other elastic fluids in other forms of motors.

Water is composed of 2 volumes of hydrogen united to 1 volume of oxygen, the union forming 2 volumes of steam; and the weight of 1 volume of steam, hydrogen being unity, is 8.98, so if air is taken as unity the density of steam at atmospheric pressure will be 0.561.

The maximum density of water is at 4° Centigrade, or 39.2° Fahrenheit. Below this point water expands until frozen at 0° C. or 32° F., forming ice, and in freezing water expands from 1 to 1.09 of its volume.

Ice melts at 32° F., and there can be no rise of temperature until all the ice is melted.

In passing from the solid to the liquid state a given weight of water takes up, or renders latent, just so much heat as would suffice to raise the same weight of water through 79° C. or 142° F. The latent heat of water is, therefore, said to be 79 thermal units C. or 142 thermal units F.

When heated to 100° C. or 212° F., in the open air

at ordinary pressure of the atmosphere at sea-level, water boils and steam is formed. In this second change of form from fluid to vapor another large portion of heat becomes latent. The thermometer would indicate no change of temperature, but in the transformation 536 thermal Centigrade units, or 967 thermal Fahrenheit units, disappear or become latent.

In scientific books and in foreign countries the Centigrade thermometer and the French decimal system of weights and measures are generally used. The Centigrade graduation makes the freezing-point 0, and the boiling-point 100. The kilogramme is used for weight, which is equivalent to 2.2047 lbs. avoirdupois. In the Fahrenheit scale, which will hereafter be used to avoid confusion, the freezing-point is 32° and the boiling-point 212°. 1° Centigrade is therefore equivalent to 1.8° Fahrenheit.

The temperature at which water boils is dependent upon the pressure. Under the exhausted receiver of an air-pump, and on the tops of mountains, the boiling-point is lower, and in steam boilers, under pressure, it may be almost indefinitely increased.

Other fluids boil at very different temperatures; some of them, such as liquid ammonia, boiling at a temperature much below the freezing-point of water.

Specific heat is the thermal capacity of a given quantity of any substance, and the thermal capacity is the quantity of heat necessary to raise the temperature 1° in the absolute thermodynamic scale which commences at the theoretical zero of —460° Fahrenheit, water being taken as the unit. The specific heat of ice is 0.513, of cast-iron 0.140, of air and approximately of other gases

under constant volume and atmospheric pressure 0.250, and of steam 0.475.

The fuel required for the conversion of water into steam constitutes the principal item of expense in the conversion of heat into work, and is the most important datum in the comparison of the economical efficiency of different systems.

The fuel usually employed is coal, but in many cases petroleum has been used to great advantage.

One pound of pure carbon requires $2\frac{2}{3}$ pounds of oxygen for perfect combustion with conversion into carbonic acid, and this quantity of oxygen would be furnished by 12.2 pounds of air, the result being 13.2 pounds of gases heated by 14,544 units of heat, and giving a theoretical absolute temperature of 5150 degrees.

Air at 32° F. volume 1 cubic foot, weighs 0.0807 lb. or 12.39 cubic feet to one pound, and 12.2 lbs. would require 151.16 cubic feet.

The greatest possible evaporation of water from one pound of carbon, if all the heat-units could be utilized, would be 14.87 pounds.

In practice it is not possible to introduce and distribute air in the exact proportion required for perfect combustion, and a portion of fuel must remain unconsumed, or a portion of the heat-units expended without useful effect in heating a surplus of air.

The best quality of coal should yield in combustion about 14,000 units of heat; but 13,000 would probably be nearer the ordinary average.

To raise one pound of water from the ordinary temperature of 60° to 212° would require 152 thermal

units. To convert 1 pound of water into steam at 212° requires 967 units in addition, and to raise this steam to a pressure of 150 pounds, temperature 360°, the specific heat of steam being 0.475, will require 148 x 0.475 = 70 units more, making a total of 1189 units.

If 13,000 units could be utilized in 1 pound of coal, the evaporation would be 11 pounds of water from 60° F.; but in ordinary practice in locomotive engines the evaporation is about 6 pounds, and in small motors even less.

Steam at 150 lbs. pressure has 3 cubic feet of volume per pound, and 6 pounds would occupy 18 cubic feet of space in the boiler.

The full value of the thermal units contained in the boiler steam cannot be utilized. The exhaust in a locomotive is always under considerable pressure, which reduces the mechanical effect. The exhaust steam condensing into water loses the 967 thermal units required for its change from fluid to vapor with its 1700-fold increase of volume. There are also other losses between the boiler and the cylinders by radiation and friction, so that to calculate the useful mechanical effect in a small street motor from the number of thermal units in the boiler presents too many elements of uncertainty for the results to be relied upon.

Ordinary locomotives on railroads evaporate from 20 to 150 gallons of water per mile run, the average being 40 for passenger engines and 80 for freight. The Reading Railroad used per ton-mile 0.31 pound for passenger engines and 0.11 for freight.

The consumption of coal averages 80 pounds per square foot of grate surface per hour; the evaporation

not more than 6 pounds of water per pound of coal, or about one-half the theoretical possibility.

The consumption of steam per horse-power per hour is 25 pounds, the maximum possible evaporation 600 pounds per square foot of grate surface. The evaporation at 6 pounds of water to 1 pound of coal and 80 pounds of coal per hour per square foot of grate would be 480 pounds, yielding 19.2 horse-power per square foot of grate surface.

The horse-power required to propel an ordinary street motor operated by steam can be determined with a considerable degree of accuracy from observations made by the writer in 1879 on the power required to propel street motors by compressed air.

In these tests the motor cylinders were $6\frac{1}{2} \times 13$ inches, the number of revolutions of wheels per mile 720, the piston travel per mile in the two motor cylinders 3120 feet, the speed 6 miles per hour, the piston travel 18,120 feet per hour, the mean piston pressure 56.64 pounds per square inch on an area of 33.18 square inches, making total piston pressure 1879 pounds.

Then, $\frac{18120 \times 1879}{33000 \times 60} = 17.2$, horse-power applied to piston.

Wellington, in his *Economic Theory of Railways*, page 451, states that the consumption of steam per horse-power per hour is rarely better than 25 pounds, and often much worse.

If, then, the evaporation under the pressure assumed of 150 pounds per square inch be taken at 6 pounds of water to 1 pound of coal, and if it be assumed that 17.2 horse-power in cylinders will require at least 20 horse-

power in boilers, the consumption of coal per hour would be $\frac{20 \times 25}{6} = 83$ pounds, and per mile 14 pounds, which, at 3 mills per pound, or \$6 per ton, would be 4.2 cents per mile. For small street motors this result seems to be in excess of the true average.

Steam motors should run 100 miles per day, and, allowing for repairs, 300 days in the year, or 30,000 miles. They would cost about \$3000; while 10 horses to one car, running the same distance, would cost \$1500; but as a motor with 50 per cent. increase of capacity could haul two cars and at greater speed, the number of motors required would be less than the number of cars, and the excess in the cost of motors over horses would not be very great.

If a road be supposed 6 miles long, requiring a round trip of 12 miles, and a steam motor to run at 8 miles per hour, and 2-minute intervals, the round trip would require 90 minutes, and the number of motors, without allowance for reserve, would be 45.

If operated by horse-power at a speed of 4 miles per hour, and 10 horses to a car, the round trip would require 3 hours; the cost of horses would be about the same as the cost of motors, but the number of cars would be doubled.

If, in consequence of municipal restrictions or other causes, the speed should be limited to 6 miles per hour, the number of motors and cars would be increased 33 per cent.

Taking, as a basis of comparison, 2-minute intervals between cars, speed of horses 4 miles per hour and of motors 6 miles, and a reserve of 25 per cent., length of

road 6 miles and round trip 12 miles, the number of cars required for horses would be 112 and for motors 75, making a saving of $37,000 in car equipment with steam motors.

The reduced number of cars would reduce car repairs about $\frac{1}{3}$ of a cent per car-mile, and conductors $1\frac{1}{3}$ cents.

The cost of horses would nearly balance the cost of motors, taking into consideration reduced time of round trip.

Engineers would be more expensive than drivers, but the number would be less.

Fuel would cost less than horse-feed. Shoeing would balance repairs.

Trautwein gives the amount of coal consumed per ton-mile in ordinary passenger trains as 0.31 lb.; but as traction on roads in good order is at least one-half as much as on street railroads per ton, the proportionate consumption of coal may be taken at 0.65 lb. for steam motors.

Assuming the weight of the motor at 8 tons and of the car at 5 tons, the total will be 13 tons, and the consumption of coal with these data about 9 pounds per mile.

No data are accessible for an accurate determination of the coal consumed in a small steam motor for street service, and the foregoing estimates include many elements of uncertainty. Another estimate will be attempted on a basis that would seem to be more reliable.

The consumption of free dry air in the Hardie motor of 8 tons was found to be 720 cubic feet per mile run. One pound of steam at 212° = 27 cubic feet; 720 cubic feet = 27 pounds of steam, requiring 5 pounds of coal for 8 tons; 13 tons would therefore require 10.6 pounds

for a train of motor and car. It will probably be safe therefore to estimate the consumption at 10.6 pounds per mile run. The motor not being suitable for carrying passengers, a weight of 13 tons is required as against 8 tons with equal carrying capacity in systems in which car and motor can be combined. The cost for coal in this system will be 2.65 cents per train-mile.

The repairs of cars drawn by motors can be taken as the same cost per car-mile as by horses, which is $1\frac{1}{3}$ cents, and the cost per day $76.80.

Cost of Engines.

The cost of small engines is much larger in proportion to weight than the cost of large ones. Large engines cost $286 per ton of weight; small engines from $383 to $400 per ton. An engine weighing 8 tons should cost, at this rate, $3200. The smallest mine engines manufactured at the Baldwin Locomotive Works cost $2500.

Repair of Motors.

The cost of repairs on ordinary passenger engines is about 7 cents per mile run. Small engines will cost much more in proportion to weight. It is possible that the cost of repair of street motors may be covered by 4 cents per mile run.

Depreciation.

The depreciation of motors will be taken at 15 per cent., of cars 5 per cent., of buildings 3 per cent.

Plant Required.

Double the track-room will be required for cars and motors that would be needed for the cars alone; and repair shops will also be necessary for repairs of engines.

Plant Required for 6 Miles of Double Track to be Operated by Steam Motors.

Real estate, motor and car-sheds, shops and offices, 40,000 square feet land, $1.50 . .	$60,000
Buildings and machinery for repairs . .	100,000
	$160,000

Street Construction.

1 mile double track	$20,000
9282 sq. yds. paving, $3	27,846
Cost of one mile	$47,846
Cost of six miles	287,076

Rolling Stock.

75 steam motors, $3000	$225,000
75 trail cars, $1000	75,000
	$300,000

Summary Cost of 6 Miles.

Real estate	$160,000
Track and paving	287,076
Rolling stock	300,000
Miscellaneous expenses	20,000
Cost of 6 miles	$767,076
Cost of 1 mile	$127,846

Cost of Operation of 6 Miles Double Track For One Day With Steam Motors.

30 tons coal at $5 per ton	$150.00
Waste, oil, and grease	25.00
Depreciation of plant and rolling stock	127.00
60 conductors, $2	120.00
60 engineers, $3	180.00
60 firemen, $1.50	90.00
Car and engine house expenses	42.00
Motor repairs, 5760 miles, 4 cts.	230.40
Car repairs	76.80
Track service	16.00
Repair of track and buildings	60.00
Clearing track, train and shop expenses	25.00
Accidents	20.00
Legal and other expenses	10.00
General and miscellaneous expenses	50.00
5760 train-miles cost	$1222.20
Cost per car-mile	21.22 cents.

III.

AMMONIA MOTOR.

AMMONIA, at ordinary temperatures, is a permanent gas formed by the union of three volumes of hydrogen with one of nitrogen, condensed into two volumes. Its density is 0.596, air being 1.000.

When condensed into a liquid the density is 76, water being 100.

Ammonia vapor at 60° Fahrenheit gives a pressure of 100 pounds to the square inch, while water, to give an equivalent pressure, must be heated to 325° F.

2

The volume of ammoniacal gas under 100 lbs. pressure is 980 times greater than the space occupied by its liquid, while steam under the same pressure occupies a space only 303 times greater than water.

Ammonia liquefies under a pressure of 17 atmospheres, 250 lbs. per square inch, at ordinary temperatures, and by cold alone at 40° below zero.

At 103° F. below zero, and a pressure of 20 atmospheres, ammonia is condensed into a white, transparent crystalline solid, which melts at 103° F. below zero.

The latent heat of ammoniacal gas is 860, that of steam being 967.

The solubility of ammoniacal gas in water is remarkable. At a temperature of freezing, water will absorb more than a thousand times its volume; at 50° F. more than 800 times, and at 70° 500 times.

Knight's *American Mechanical Dictionary* states that ammoniacal gas is condensed into a liquid at the pressure of the atmosphere at a temperature of —37.3° F., or —38.5° C. At the boiling-point of water it requires 61 atmospheres. At the freezing-point of water it requires 5 atmospheres at 70° F., a pressure of 9, and at 100° F., a pressure of 14.

The same authority states that the economy of fuel to obtain a given pressure is very great, being only about one-fourth the amount required to obtain an equal pressure by the use of steam.

As ammonia is absorbed the water becomes specifically lighter, while its volume is being augmented about one-third. As the absorption of the gas goes on, the water becomes heated and the latent heat of the gas reappears as sensible heat. It is in this property that water pos-

sesses, of absorbing so large an amount of the gas and of becoming heated while absorbing it, that the practicability of using ammoniacal gas as a motive power consists, the only agency for producing motive power being heat.

In 1871 an ammoniacal motor was constructed at New Orleans by Dr. Emile Lamm. It was tested and reported upon by a committee of which General G. T. Beauregard was chairman, and the report of this committee, with the accompanying statement of the inventor, Dr. Lamm, is an extremely interesting document from which much of the information here given has been derived.

Dr. Lamm does not claim for ammonia the ability, with a given expenditure of heat, to produce a larger initial force than with water, but the chief advantage claimed by him appears to consist in the fact that the production of the force at a low temperature apparently allows a greater portion to be utilized. He remarks: "The experience of nearly a century since the perfection of the steam-engine has left the world in possession of one invaluable fact, that any system of mechanics, however ingenious, not based on a like expenditure of fuel in the heating of liquids, while all obey the same laws of expansion, has invariably proved a failure. It can now be positively asserted that we cannot, with a given quantity of heat, obtain more force with one element than with another. We must look for improvement in the machine and not in the law.

"In the various forms that matter assumes the physicist sees only one primary cause—heat. A unit of heat added to a given weight of any substance will produce

a like development of force in all equal weights of matter, however dissimilar in physical appearance or properties.

"One holding such views could not be expected to claim for himself a discovery to supersede steam as a general agent of mechanical force.

"In that most remarkable quality which water possesses of being converted by heat into a medium which is as yet the cheapest of all mechanical agents, ammonia stands fully the equal of water in economy, with this difference only, that the cost of the necessary quantity of ammonia to run an engine enters as first cost, with a yearly loss of 25 per cent. to be added thereon—the price of water being nominal. While ammoniacal gas is equal in every other respect to steam, except in the first cost of the material generating it, it possesses qualities that will always insure its use as an economical power in all cases where steam, from the very nature of its production, could not be used to the same advantage. For example, the smallest steam engine necessitates a personal attendance but little less costly for one-horse power than for one hundred. So it is with the manufacture of ammonia for horse-cars. A still of 100 horse-power to supply 100 cars will cost but little more for attendance than a 1 horse still. But here the resemblance ceases. The large steam-engine does not allow of any division, while an ammoniacal still of 100 horse-power can be divided into 100 ammoniacal engines without any additional expense. This is owing to the fact that ammoniacal gas can be liquefied in one single large establishment, from which the liquid can be transported at any time thereafter to any distance from the furnace which generated it, and

then and there be made to act upon an engine with all the pristine force of tension which was imparted to it by a fire whose ashes have been cold for months or years past."

Dr. Lamm concedes that the point at which a liquid may boil below the common temperature makes but little difference practically between the heat necessary to evaporate into steam a given amount of water which boils at 212° F., and one that boils at 40° minus, such as ammonia: the real and only difference being, comparatively, that of radiation in favor of the liquid that boils at 40° minus, and even the above difference would seem to be more apparent than real.

"If it was necessary to heat ammonia or a street-car by means of a furnace, ammonia, then, would offer but little advantage over steam."

It appears, therefore, that the principal advantage claimed by the inventor, Dr. Lamm, in the use of ammonia as a substitute for steam, is that only one fire at a central point will be required for all the engines on the road, the power in the shape of liquid anhydrous ammonia being bottled up for use when and as required; also, some advantage by diminished loss of heat by radiation in consequence of the low temperature at which the gas is used. It is not claimed that the natural law by which a unit of heat is the equivalent of 772 foot-pounds of work can be evaded. Work done is always heat lost. The latent heat of the ammonia gas reappears in the water of condensation, less the amount expended in work, and when the aqueous solution is pumped back into the still all the lost heat must be restored by the combustion of coal. In consequence of the superior

evaporative power of stationary as compared with small locomotive boilers, the ammonia engine should effect a large saving of fuel, if not counterbalanced by attendant disadvantages, as compared with small steam motors, but as compared with the pneumatic or other systems where the power is also generated by a large central plant, and where there is no loss by radiation or condensation, the advantages are not apparent. In fact, Dr. Lamm himself abandoned the ammonia engine after a short trial in favor of hot water, which was used for some years on the street roads at New Orleans, and then the company returned to mule-power.

Having written to General Beauregard to ascertain the reasons for the abandonment of ammonia when the report of the committee appointed to test the invention had been so satisfactory, the General replied, under date of December 23, 1892, that no difficulty was encountered in the use of Lamm's Ammoniacal Motor; but, while experimenting with it, Dr. Lamm discovered the "Heated Steam Motor," which he preferred as being *cheaper* and *less troublesome*, and the board of directors, of which General Beauregard was president, agreed with him. After some years a new board of directors came into control, who abandoned the hot-water motor and returned to mule-power.

After twenty-one years the subject of ammonia motors appears to be again occupying public attention, and it is therefore proper that a brief description of Lamm's Ammonia Engine, as used in 1871, should be given.

LAMM'S AMMONIA ENGINE.

The patent bears date July 19, 1870, and describes an addition to a steam-engine of water-chambers inclosing the piston-rods and valve-stem, so as to render it capable of being worked by ammoniacal gas instead of steam, without any loss of the gas, which is returned to the common tank, while the exhaust is re-absorbed by a weak solution of aqua ammonia.

The second part of the invention relates to the application of liquefied ammoniacal gas, contained in a considerable number of iron tubes, as the liquid from which, instead of water, the motive power of the engine is derived.

The third part relates to a weak solution of aqua ammonia, contained in a tank, in which the iron tubes are immersed, and in which, also, the exhaust pipe of the engine is made to dip near the bottom. The gas exhausted while the engine is working is re-absorbed by this weak solution of aqua ammonia until the solution becomes saturated. The gradual re-absorption of the gas by the weak solution causes the latent heat of the gas to re-appear. This re-transfer maintains a constant temperature within the tubes, resulting in an undiminished pressure from expansion of the liquefied gas, which maintains the motive power at its maximum tension.

The process of liquefying the ammoniacal gas is rendered continuous by a fresh, concentrated solution pumped back into the boiler to replace the weak solution, which is drawn off from its bottom.

It is claimed that 3 pounds of coal will evaporate 3 gallons of water, while 3 pounds of coal will produce 4

gallons of liquid gas. One gallon of water under $6\frac{1}{2}$ atmospheres at 320° F. = 295 volumes of steam; one gallon of liquid gas under $6\frac{1}{2}$ atmospheres at 50° F. = 983 volumes of gas.

In the tests made by General Beauregard 1.44 gallons of liquefied gas were consumed per mile.

The weak solution put in at 15° Baumé was found to weigh 23° Baumé at end of trip, having been increased by absorption of gas 8°.

5 gallons of commercial aqua ammonia of solution 25° Baumé can be delivered at New Orleans at 40 cents per gallon. The liquefied gas would therefore cost $2 per gallon.

$73\frac{1}{2}$ pounds of bituminous coal liquefied in 38 minutes 18 gallons of gas from the solution of aqua ammonia at 23° Baumé.

Cost of Distillation. Time, 38 *Minutes.*

Coal, $73\frac{1}{2}$ lbs. at $5 per ton	$0.18375
One engineer, $5 per day, fireman, $2, (38′) .	0.36939
Machinery, $3 per day	0.15831
Cost of liquefying 18 gallons	0.71145
Hence, 1 gallon would cost	0.039525

or, about 4 cents. 1.44 gals. = 1 mile will cost $5\frac{3}{4}$ cents.

This estimate, based on time 38 minutes, assumes proportion of continuous operation for the whole day. Any intermission would add to the cost, and the cost, as will be seen, is very largely in excess of the cost of compressed air per mile run.

Estimate for Running 25 Cars 95 Miles Each Per Day.

MADE BY COMMITTEE.

Cost of making 3410 gallons of liquefied ammonia for 25 cars, running 2368 miles per day :—

Interest on plant, $15,000, at 20 per cent. . .	$ 8.22
Interest on ammonia, $864, at 8 per cent. . .	0.19
Loss of ammonia, $864, at 25 per cent. . .	0.60
Coal, 4.64 tons, $5	23.20
Labor	14.00
	$46.21
One car per day will cost	1.85
One mile will cost	.019
or, nearly 2 cents per mile.	

Observation.—This sum of 2 cents per car will represent the cost of fuel only, and was based on the data furnished by the tests made by the committee, but Dr. Lamm states, on page 15 of his report, that the engine used on the car was *two horse-power*. This was probably an under-estimate, although the motor was no doubt a very small affair. An ordinary street steam motor should develop from 15 to 20 horse-power. 2 cents for 2 horse-power of the motor would be very nearly as expensive as horse-power.

If, as stated, it required 1.44 gallons of liquid ammonia to run the car one mile, and the cost of distillation was 4 cents per gallon, then the cost of ammonia would be 5.76 cents per mile, instead of 2 cents. The 2 cent estimate was made upon hypothetical data, and the 5.76 cents per mile was for a 2 horse-power engine. These

estimates cannot be relied upon as a basis for calculation of expenses on a large plant.

These tests must have been made under very unfavorable conditions in regard to track and machinery, and could not have exhibited the full economic power of ammonia.

Another estimate of the cost per mile run will be based upon the actual performance of the Pneumatic Motor, assuming that a cubic foot of ammonia gas, at a given pressure, will produce an equivalent mechanical effect to a cubic foot of air under the same pressure.

It has been ascertained that 720 cubic feet of free air compressed to 10 atmospheres will run a motor one mile. 720 cubic feet of free air = 72 cubic feet at 10 atmospheres.

1 cubic foot of liquid ammonia = $7\frac{1}{2}$ gallons, at 4 cents per gallon for distillation costs 30 cents, and yields 639 cubic feet of gas under 10 atmospheres pressure.

The cost of one mile, 72 cubic feet = $30 \times \frac{72}{639} =$ 3.4 cents.

This allows for no losses. It is possible that 4 cents would cover the expense. This is a little below steam, which was estimated at 4.2 cents per mile run for fuel only.

The Ammonia Motor has been revived by a New Jersey company operating under new patents. The writer called at the office of the company in New York, and was very courteously received by the treasurer, who referred him to the draftsman at the power-station for detailed information in regard to plans and principle of operation. The motor was not ready for exhibition, but the plans were shown of a compact, well-arranged ma-

chine for an independent motor of capacity sufficient for one or two cars, the dimensions of which were given as follows:—

Size—Height, 5′ 6″. Length, 9 feet. Width, 6 feet.

Weight, 3 tons. Horse-power, 25.

Tractive force, 1300 pounds. Capacity for liquid ammonia, 44 gallons. Capacity for water, 180 gallons. Driving-wheels, 2 feet diameter. Outside connections.

Motor calculated to run 14 miles with one charge. Speed, 6 miles per hour. Cost of motor as stated at office, $3200; at power-station, $2300.

To run 1 mile with 8 tons load will require 3 gallons of anhydrous ammonia.

The plant to redistill 400 gallons in 10 hours costs $3500. As this apparatus may be considered as still in the experimental stage, no data for estimates have been given. If the cost of redistillation should be as great as in the New Orleans tests the cost per mile run would be excessive, amounting to 12 cents, but it is probable that this would be greatly reduced, and the company claims the ability to redistill the ammonia at a cost of 1 cent per gallon, or ¼ the cost at New Orleans.

The claims of the company are: Great economy as compared with horse, trolley, or cable system, both in plant and in operation, which claims are probably well founded; also, ability to run 1 mile with 3 gallons of anhydrous ammonia. Pressure, 150 pounds per square inch; wastage, 10 per cent.

A 16-foot car can run 25 miles before recharging. Cost of preparing the ammonia, 1 cent per mile. Total of all operating expenses, 7.68 cents per car-mile.

The above statements are supported by record of tests

made at Jackson Park, Chicago, April, 1892, and are given as the claims of the parties interested. The writer had no time or opportunity for verification of these claims, and no information as to the dimensions and weight of the motor in which the tests were made.

From the data given in the foregoing pages in regard to the ammonia motor, and the principles upon which it operates, the reader can form his own opinions as to the probability of results verifying the claims that have been advanced.

IV.

THE HOT-WATER MOTOR.

THIS motor, otherwise known as the fireless locomotive, was the successor of the ammonia engine, and was used for some years on the street railroads of New Orleans under the name of the Angomar Motor.

The efficacy of this motor depends upon the great capacity for heat of water, in consequence of which it is claimed that a sufficient quantity of energy can be stored in a reservoir to suffice for a run of ordinary length.

Under the normal pressure of the atmosphere, water boils at 212° Fahrenheit; but the boiling-point may be reduced or elevated by a variation of pressure, and where pressure is reduced, the excess above the temperature corresponding to the reduced pressure is converted into steam at the same temperature with the pressure due thereto.

The following table gives the absolute pressures, including the pressure of the atmosphere and the Fahrenheit temperatures corresponding thereto :—

P.	T.	P.	T.	P.	T.
14.7	212°	145	356°	360	432°
15	213	150	358	370	435
20	227	155	362	380	437
25	240	160	365	390	440
30	250	165	367	400	442
35	259	170	370	410	444
40	267	175	372	420	446
45	274	180	374	430	448
50	281	185	376	440	451
55	287	190	378	450	453
60	293	195	381	460	455
65	298	200	383	470	457
70	303	210	387	480	459
75	307	220	390	490	461
80	312	230	394	500	463
85	316	240	398	525	466
90	320	250	401	550	471
95	324	260	404	575	476
100	328	270	407	600	480
105	331	280	411	650	488
110	335	290	413	700	495
115	338	300	416	750	502
120	341	310	419	800	508
125	344	320	422	850	515
130	347	330	424	900	521
135	350	340	427	950	526
140	353	350	430	1000	532

The latent heat of steam at 212° is 967°, making the total thermal units in one pound of steam, above zero, 1179, and above the freezing-point, 1147, of Fahrenheit's scale. From this point the total units increase in a ratio determined by the formula of Regnault; and the sum of the latent and sensible units is not a constant quantity, as Watts supposed it to be, and which

opinion was for a long time assumed to be correct. The total units at 212° above zero being 1179, the increase is gradual until, at a temperature of 428°, it becomes 1244, an increase of 65 units in 216°. The latent heat at 428° is 816 units, instead of 967 at 212°.

The volume of steam at 212° is 1700 times greater than the water from which it was produced.

A pound of steam at 212°, under a pressure of 14.7 pounds per square inch, occupies a volume of 26.36 cubic feet. Under any greater pressure the volume will be proportionately reduced.

The specific heat of water being unity, steam is 0.475.

When a portion of water at a high temperature is converted into steam by reduced pressure, the remaining water is cooled to the extent of the thermal units required for the conversion of the water into steam—a fact that appears to have been neglected in some computations of the length of run of which the hot water or fireless locomotive is capable.

The following table gives pressures, volumes, thermal units above 32°, and latent heat corresponding to the temperatures in the first column :—

Temperature.	Pressure.	Volume of 1 pound.	Total thermal units above 32°.	Latent thermal units.
212	14.7	26.36	1147	967
221	17.5	22.34	1149	960
230	20.8	19.03	1152	954
239	24.5	16.28	1155	948
248	28.83	14.00	1158	942
257	33.71	12.09	1160	935
266	39.25	10.48	1163	929
275	45.49	9.12	1165	922
284	52.52	7.97	1168	916
293	60.40	6.99	1171	910
302	69.21	6.15	1174	904
311	79.03	5.43	1177	898
320	89.86	4.81	1179	891
329	101.9	4.28	1182	885
338	115.1	3.81	1185	879
347	129.8	3.41	1188	873
356	145.8	3.06	1190	866
365	163.3	2.75	1193	860
374	182.4	2.48	1196	854
383	203.3	2.24	1199	848
392	225.9	2.03	1201	841
401	250.3	1.84	1204	835
410	276.9	1.67	1207	829
419	305.5	1.53	1210	823
428	336.3	1.39	1212	816

As an illustration of the use of this table, suppose 10 pounds of water, at a temperature of 428° and pressure of 336 pounds per square inch, are confined in a tight vessel, and that 2 pounds are permitted to blow off into the atmosphere.

The 10 pounds of water contain 4280 thermal units, and the 2 pounds converted into steam and escaping will remove 1934 units, leaving 2346 units in the remaining 8 pounds of water, or 293 units per pound. The temperature of the 8 pounds of water will therefore be reduced to 293° from 428°, and the pressure from 336 pounds to 60 pounds per square inch.

This illustration will suffice to show how rapidly pressure is reduced in a tank of superheated water by the escape of a portion in steam, the remaining water being taxed to furnish the heat that becomes latent in the transformation.

In an old number of the *Railroad Gazette* is found a description of the New Orleans Fireless Locomotive, from which the following extracts are given :—

The cylindrical tank is 31 inches in diameter and 9 feet long, with capacity for hot water of 300 gallons. Driving-wheels, 30 inches diameter. Wheel-box, 5 feet 7 inches. Cylinders, 4½ inches diameter, 10 inches stroke. Weight of engine, with full tank of water, 8700 pounds. Tank charged from stationary boiler, which has a pressure of 220 pounds per square inch. The engine ran 6 miles with an ordinary street car. At the end of the run the pressure was reduced to 40 pounds.

No complete information has been obtained about the performance of these engines. Difficulty was encountered in charging the boilers with water all heated to a uniform temperature of 390° (220 pounds pressure). The trouble appears to have been that only the surface of the water became heated where the connection was made with the tanks, and it was found difficult to obtain a pressure in the boiler equal to that of the tank.

In running from the stationary boiler to the place where the engine was attached to the cars, the pressure would fall from 220 to 190 pounds, but the engine would then run 3½ miles. At the end of this distance, with 60 pounds pressure, the engine would pull a car

while the steam was cut off at one-fifth of the stroke. There are no grades in New Orleans.

The difficulty referred to in the above extract shows that the boiler was replenished from the tank without discharging the cooler water which it contained on the return trip. As was to be expected, the hot water would remain on the surface, and could not mix with the colder water below until the engine had been run a short distance and the water well shaken, when the pressure at once fell 30 pounds.

To secure a pressure in the engine equal to that in the tank, the boiler must be emptied under pressure on the return trip and the water pumped back into the tank to be reheated. If the water is not returned under pressure, the temperature will fall to 212° and much heat be lost by the escape of steam and the conversion of sensible into latent heat. A still greater loss would result from wasting the water entirely.

A test of another hot-water motor, in November, 1886, gives the following data: "Cylinders, 9 by 10. Driving-wheels, 31 inches diameter. Heating surface in boiler, 188 square feet. Grate surface, 6 square feet. Mean effective pressure in cylinders, 43 pounds per square inch. Indicated horse-power of two cylinders, 43. Revolutions per minute, 155 at 14 miles per hour. Temperature at start, 280°; pressure, 48 pounds. Temperature at conclusion, 300°; pressure, 64 pounds. Duration of test, 1 hour. Time of charging, 1½ minutes. Hauled 2 double-truck passenger cars, 12½ tons each. Grade, level. Cost per mile, 1⅞ cents."

This engine was a combination of hot water and

steam. It had sufficient grate surface to develop 18 to 20 horse-power by the combustion of coal alone in the fire-box as in an ordinary locomotive; and as the pressure increased during the run, it is evident that this effect could only be produced by the consumption of coal. The results furnished no satisfactory test of the capacity for service of hot water alone. There can be no question that if the boiler can be filled at the start with hot water under a working pressure, and well protected against radiation, a smaller quantity of coal will be required for a run of moderate length than would be required if feed water were admitted cold, and it is also certain that water can be heated in a stationary tank more economically than in a locomotive.

Another report of tests of this same engine, at another time and in a different locality, gave a run of 23 miles with trailer, using 128 pounds of coal in motor and 180 gallons of water. The pressure at starting was 175 pounds. After running 3½ miles it was reduced to 155 pounds, and afterwards, at intervals, the gauge pressure was 150, 145, and 155 pounds, and at the end of the run 105 pounds.

180 gallons of water = 1350 pounds evaporated with 128 pounds of coal gives 10½ pounds of water per pound of coal. As the evaporation by consumption of coal in the motor should be 6 pounds per pound of coal, it would leave the equivalent of 4½ pounds to be supplied in the hot water from the stationary tank.

The capacity of the boiler was given as 262½ gallons.

Many of the statements made in regard to the so-called fireless locomotives are so unreasonable that no attempt will be made to criticise them. Of course, no

engine can be called fireless that has a fire-box, with 20 horse-power for the combustion of coal, and in which coal is used to help the run. Neither can a boiler which is of ordinary material and construction, subjected to a pressure of 175 pounds or upwards, either of water or steam, be considered as non-explosive. In fact, in case of rupture, a boiler filled with water at a given pressure would cause much more damage than if filled with steam at the same pressure, for the steam liberated from the water would be many times its volume.

For the purpose of comparison with other motors, it will be assumed that the run is to be made entirely with hot water; and as no data have been furnished from which to calculate the loss by radiation, these losses will be omitted.

The capacity of the boiler will be taken at 300 gallons = 40 cubic feet = 2500 pounds.

The pressure will be taken, as given in the test, 175 pounds per square inch effective, or 189.7 absolute. Temperature, 377° F.

The engine will be supposed to run until the pressure has been reduced to 60 pounds effective = 74.7 pounds absolute. Temperature, 307°.

The differences of temperature available for motor work, when converted into steam, would be 377°—307° = 70°.

Let x represent the pounds evaporated to reduce the temperature from 377° to 307°; then $2500 - x$ will be the quantity remaining at the lower temperature, and x carries off not only the 70° of difference, but also the latent heat of 967°; then $2500 \times 377 = 307$ (2500

$-x) + 1037x$. Consequently $x = 242$ pounds converted into steam, and leaving 2258 pounds in boiler at the temperature of 307°. 242 pounds of steam at the average effective pressure of 43 pounds per square inch $= 7.2$ cubic feet per pound, gives 1742 cubic feet available for propulsion.

The wheels were 31 inches in diameter or 8 feet in circumference. The number of revolutions per mile would be 660.

The cylinders were 9 inches diameter, 10 inches stroke. Capacity of 4 cylinders, 2464 cubic inches, or 1.4 cubic feet for each revolution $= 1.4 \times 660 = 924$ cubic feet per mile.

It would appear, therefore, that the hot water alone, without the aid of the fire-box, would not run the motor as much as 2 miles, since the number of cubic feet available is only 1742.

It is unnecessary to pursue the investigation further. Hot water alone cannot be relied upon to run a motor for a sufficient distance unless supplemented by coal combustion in a fire-box, which makes it, in fact, an ordinary steam locomotive; and the slight saving effected by heating the water in a stationary tank is more than offset by the inconveniences attending its use.

Cost of Plant and of Operation by the Ammonia and the Hot-water Motors.

No special estimates are required on these motors. The statement made by Dr. Lamm and General Beauregard in reference to the ammonia motor shows that it

was abandoned by its inventor and by the New Orleans Committee as less economical and more troublesome than the hot-water motor; and the statement in regard to the hot-water motor shows that it is decidedly inferior to steam, being in fact nothing more nor less than a steam engine in which the use of steam for a short distance is obviated by the substitution of hot water in the boiler taken from a stationary tank at a high temperature. The economy cannot be superior to that of the ordinary steam locomotive, and the manipulation on a large scale would be troublesome and introduce unnecessary complications.

V.

GAS MOTORS.

In all the ordinary forms of motors, as steam, air, electricity, cable, ammonia, or hot water, the original source of power is heat developed by the combustion of fuel, usually coal or wood, and transmitted by various agencies to the motor machinery.

In this transmission losses are sustained to a greater or less extent. Steam loses by radiation and condensation; cable lines lose sixty per cent. by friction and other resistances, and utilize not more than forty per cent. in car propulsion; electricity loses an equally large percentage of the original power by resistance of conductors and machinery; air by the heat generated in compression, which cannot be utilized, but the equivalent in motive energy may be restored by reheating. There is

also a loss to a small extent by friction of pipes in transmission to long distances, so that in all these cases only a portion of the thermal units developed in the combustion of the fuel can be actually utilized in the work accomplished.

In gas engines there is no transmission of heat from a furnace to the motor cylinder with its attendant losses. The combustion is effected and the power generated in the motor cylinder itself, and the power is applied directly to the piston; in addition to which, if the air is properly regulated so as to admit the proper proportion, the combustion can be perfect, the temperature a maximum, as also the expansive force due thereto.

Coal develops in perfect combustion about 14,000 thermal units; but in a locomotive only about one-half, or 7000 units, can be utilized. The cost of coal is, at 4 dollars per ton, 2 mills per pound.

Gas engines are run with gas or naphtha vapor, yielding in combustion about 28,000 thermal units per pound. The cost of naphtha is 5 cents per gallon. The specific gravity is 0.848, so that a gallon weighs 6.3 pounds, and the cost per pound is 8 mills.

As the cost per pound of naphtha is four times as great as the cost of coal, while the calorific power is also four times as great, the cost for equal units will be equal.

But naphtha, with regulated admissions of air to secure perfect combustion, has another advantage. The thermometrical temperature is higher than with coal, and as combustion is effected inside the motor cylinder, the force of expansion and the impact upon the piston are greater than could be secured by an equal expenditure of thermal units in any other fuel, hydrogen alone excepted; but the use of hydrogen is not practicable.

Gas motors have been in process of development for 6 or 8 years, and have now reached a point where the inventors claim that difficulties have been overcome, and that their efforts and expenditures have been crowned with success. Certain it is that an order has been given for 20 Connelly gas motors for street railroad use in Chicago, and one of them was nearly ready to be tested in December, 1892. The writer had the privilege of examining this machine, which appeared to be simple in construction, compact, well built, and promising satisfactory results, but without the test of experience in actual daily use for a considerable period of time, it is always unsafe to predict unqualified success in any new mechanical device.

It is not to be expected that the present gas motors will be found in practice entirely perfect; but if defects are found, remedies may be applied. There seems to be a sound principle that will in time, if not immediately, be utilized, and there can be no question that no system now in general use can compare favorably with the gas motor in the economy of fuel required for propulsion of a given weight for a given distance, within the limits of street car service. Compressed air is the only power that can secure equal or superior economy; but this power is not in use for motor purposes except in Europe, where the results are very satisfactory, even with a motor that admits of considerable improvement in mechanical details.

Description of the Connelly Gas Motor.

This is a gas motor carrying its own store of fuel for a day's run, and the fuel used is the heaviest grade of

naphtha, which will not vaporize at the temperature of the atmosphere. It is carried in a closed tank, which is again inclosed in a radiator filled with hot water constantly furnished by the engine cylinder. The radiator performs important double service, cooling the cylinders of the engine and warming the carburetter. The circulation of the water from the cylinder to the radiator and return is continuous. The inner vessel or carburetter is filled with an absorbent material, which absorbs the charge and leaves no liquid to be lost should a leak occur. Air is drawn automatically through the absorbent material, thoroughly carburetted, and supplied to the engine in exact proportion to the power required. There is not the least element of danger attending the operation of this system. The gas is ignited by an electric spark.

The principle of all gas engines is speed; their speed cannot be varied like the steam engine, but they must run at a nearly uniform rate; therefore special mechanism was required for transmitting power to the axle at any desired rate of speed. It was absolutely essential to complete success that this should be accomplished, and in such a manner that the speed of the car could be varied at will of the driver by moving a single lever.

The mechanism employed for this important service is positive in action, noiseless, and durable. The wearing parts are easily, quickly, and cheaply replaced. It prevents giving shock or jar to the car when starting, and, above all other advantages, transmits maximum power when driving a car at minimum rate of speed.

In the transmission of power by friction, it is necessary that the contact pressure should vary in proportion

with the power transmitted. This is accomplished automatically by means of a right and left screw nut, operated by an eccentric extension of the hand lever, so that any movement of the lever in either direction, to vary the speed, changes the pressure of contact correspondingly, thus securing maximum pressure on grades or curves, and minimum when running at full speed. This is one of the most important features of the device, as it would be impracticable to run at full speed with the same contact pressure that is required when starting on grades or curves.

The above brief description has been furnished by the inventor.

Cost of Operation.

It is claimed by parties interested that the cost of operating this motor per day (14 hours), ninety miles each, is as follows:—

	Cents.
Fuel, 14 gallons naphtha, 5 cts.	.70
Lubrication	.10
Care (one engineer to 10 motors)	.30
Repairs	.30
Total cost per day	1.40

Or $1\frac{55}{100}$ cents per car-mile, not including driver or conductor.

The motors are proposed of two forms. One an independent motor designed for use on city roads where conductors are employed. These are independent motors, eight feet long, the driver standing in the centre and operating the motor in either direction without changing his position. The weight is 5800 pounds, and it is said to be

capable of hauling one standard 16-foot car heavily loaded up grades of 5 per cent. On grades not exceeding 2 per cent. it can easily handle 2 cars. The maximum speed attainable is 12 miles per hour, but the gearing can be changed to secure a speed of 16 miles per hour where such speed would be allowed by the authorities.

The cost of this motor is given at $2500.

The combination motor has an upper deck, and can be operated with or without conductor; designed for suburban roads. The machinery occupies 6 feet of the forward end, leaving room inside for 14 passengers and for 20 on the outside. The combination motor can haul a trailer in addition on roads of 2 per cent. grades.

As the gas motor has not yet passed the experimental stage, it would be rash to assert that all expectations and promises can at once be realized. That there is a future for this system seems probable, but difficulties will no doubt be experienced. The charge of air in proportion to naphtha vapor must be accurately determined and automatically regulated to admit the proper quantity; the electrical apparatus must produce the spark for ignition at the proper moment; the circulation from the cylinders to the carburetter must be constant, regular, and of the proper temperature for vaporization. If the engine should stop for a time and the water cool, there will be delay in starting, unless the water can be discharged and the space occupied by it refilled with hot water from a stationary tank so as to secure without serious delay the temperature necessary for the evaporation of the naphtha. If stopped on the track by blockades or other causes, the machinery must be

thrown out of gear, but the engine kept running to maintain the circulation and prevent cooling, and this will add to the consumption of fuel, the estimate having been made on the supposition of constant movement. The friction of contact with the driving disk must be sufficient to overcome resistances without stopping.

Where a very large plant is required, it may possibly be found advantageous to erect apparatus to manufacture gas and use it compressed in iron cylinders instead of the carburetter, in order to reduce the delays at starting to a minimum.

The best that can be said of gas motors at the present time is that they promise well in the future; but actual use on a scale of considerable magnitude will be required to develop defects, inconveniences, and objections, if any exist, and to inspire confidence in their economy and efficiency.

Taking the data furnished by the patentee, which is 14 gallons of naphtha for a run of 14 hours in an independent motor of 5800 pounds, and assuming that the consumption of fuel must be in proportion to the weight of the train carried, and also that a trail-car of 5 tons or 10,000 pounds must be carried in addition to the motor, the weight of the train would be nearly 3 times as much as the motor itself, and the consumption of naphtha for 14 miles = 42 gallons, if the 14 gallons were required for the motor alone. It is claimed, in the description of the Connelly gas motor, that it is capable of hauling a passenger car in addition; but it is not stated that this work can be done without an additional consumption of fuel; but even assuming that the 14 gallons of naphtha will carry both the motor and car a distance of 84 miles at 6 miles per hour, the cost of fuel would be

$8\frac{1}{3}$ mills per mile, which is more than the cost of fuel alone for the compressed air motor.

In addition to this, it must be observed that the gas engine must continue to run, with the machinery out of gear, when the motor is standing and making no mileage; also that house-room must be provided for both motors and cars, as in the case of steam, which will increase the investment in real estate and the interest on plant.

VI.

THE PNEUMATIC OR COMPRESSED AIR MOTOR.

After an extended investigation, commenced in 1879 and continued recently, with a long interval for observation of other systems, the writer is confirmed in his original conclusion that, for the operation of city and suburban roads—whether surface, elevated, or underground—no other motive power can compare favorably with compressed air, either in cost of plant, economy of operation, freedom from all objections, or the possession of incidental advantages.

Those who have not examined the subject almost invariably object that double the power is required to compress air that can be utilized in actual work from the air where compressed, and assume a necessary serious loss.

It may be true that double the power may be required; but suppose the air is compressed by a water-power, otherwise unemployed, that costs nothing except the first outlay for the machinery for its utilization:

might not the power be cheaper than steam, even if only 10 per cent. could be utilized?

The actual facts are that air can be compressed by the use of the best compound expansion stationary engines in which double the useful effect can be secured per pound of coal as compared with steam motors. This alone would at once place air on a par with steam; but in stationary engines a quality of coal can be used that costs less than half as much as the coal required for locomotives, and this raises the economy of air to double that of steam in small motors.

But this is not all. It has been proven by repeated tests, both in Europe and America, that the simple device of passing the air through a small tank of hot water before admission to the motor cylinders again doubles the useful effect, and at the same time prevents all inconvenience from the production of frost at the exhaust, and this makes the economy 4 to 1 as compared with steam, the cost of reheating being merely nominal.

In fact, air is the cheapest power that can be used for the operation of street railways, and it is one against which none of the objections that apply to other systems can be urged. Why capitalists and engineers have neglected it so long is beyond comprehension. It can only be explained upon the ground of ignorance of facts from failure to investigate.

Air can be transmitted to long distances without any loss by condensation or radiation, as with steam; and the loss by friction, in pipes of proper diameter, is inconsiderable, even at a distance of miles.

The importance of air as a motive power for city railroads demands a careful consideration of its claims.

Properties of Air.

Air is composed of about 23 parts by weight of oxygen and 77 parts of nitrogen.

By volume the proportions are 21 of oxygen to 79 of nitrogen.

At a temperature of 60° F., its weight is $\frac{1}{815}$ that of water = 0.0765 lb. per cubic foot.

At a temperature of 32° 12.433 cubic feet = 1 pound.

The specific heat of air at constant pressure and with increasing volume is 0.2377, water being 1.

In doubling the volume of air the units of heat expended are, as given by Clark, 117.18 (other authorities, 115.8).

If the temperature be doubled without adding to the volume, the units expended will be 83.22. To double the volume in addition requires 33.96. Total, 117.18.

The specific heat of air in raising temperature without increase of volume is 0.1688.

In compressing air from a temperature of 60° to one-half its volume under an effective pressure of 15 lbs. to the square inch the temperature will be raised to 177°, and the increment of temperature will be 117°. But in continued compression to 30, 45, 60, 75, 90, 105, and 120 pounds the temperatures are successively 255°, 317°, 369°, 416°, 455°, 490°, and 524°, and the successive increments 77°, 62°, 52°, 47°, 39°, 35°, 34°.

The capacity of air for holding moisture is affected by its volume and temperature, but apparently not by its density. It appears from observations made by manufacturers of compressed plant that air compressed to 50 atmospheres contains no more water than air at the same

temperature under one atmosphere, consequently $\frac{49}{50}$ of the water is removed during compression, and the air becomes so dry that no frost can be formed in the exhaust. Even when air is cooled by passing through water no additional quantity of moisture can be taken up. The compressor used on the Second Avenue Railroad in 1879 cooled the air by passing it through a tank of water under pressure, yet no frost was formed at the exhaust. It is now considered preferable, in the most improved construction, to cool the air without direct contact with water.

As every thermal unit is equivalent to 772 pounds raised one foot, it is evident that if air could be compressed without elevation of temperature and loss of heat in cooling much would be gained. Something has been accomplished in this direction, but complete isothermal compression is unattainable. Adiabatic compression, or compression attended by evolution of heat, is alone possible; but at high pressures the loss is proportionately less, as has been shown, and the storage capacity of reservoirs is, by increased pressure, increased for longer runs.

It was observed by Mr. G. H. Reynolds, of the Delamater Works, that the heat liberated in proportion to the power secured was much less at high than at low pressures. Satisfactory explanation can perhaps be given. Imagine a vessel containing one pound of air at ordinary tension 13 cubic feet, the base one square foot and height 13 feet. If, by means of a piston, this air should be forced into one-half the space, or $6\frac{1}{2}$ feet, the pressure would be increased to 30 pounds, and the work done would be 21,528 foot-pounds. One pound

of water raised 1° is equivalent to 772 foot-pounds, and as the specific heat of air is 0.238, $772 \times 0.238 = 184$, the foot-pounds expended in heating 1 pound of air 1°. Then $21{,}528 \div 184 = 116° =$ the heat liberated in compressing one pound of air into half its volume.

Now suppose the $6\frac{1}{2}$ cubic feet of air should be again compressed one-half, or to $3\frac{1}{4}$, the final pressure would be 60 pounds, and the space $3\frac{1}{4}$ feet, and the work 21,528 foot-pounds as before, representing 116° of heat. But with these 116° of heat the pressure has been increased from 2 atmospheres to 4, and in like manner from 4 to 8, from 8 to 16, and from 16 to 32, would each require but 116°, and at the end 16 atmospheres of additional pressure have liberated only as much heat as one atmosphere at the commencement; assuming that the heat when liberated has been absorbed so as to secure isothermal contraction of volume.

It must be remembered, however, that if the pressure should be increased to 16 atmospheres, the volume would be diminished to $\frac{1}{16}$, and if the air should be used at full pressure throughout the stroke of a piston no advantage would be gained. Very high pressures are, however, always used expansively, and if air at 500 pounds should be cut off at $\frac{1}{16}$ of the stroke, the gain over an equal weight of air at 250 pounds cut off at $\frac{1}{8}$ would be 32 per cent.

Where temperature is considered, the results are quite different. The tables for adiabatic compression give from one atmosphere to two, an increase per one atmosphere of 115.8°. At 8 atmospheres the increase is 36.1, at 10 atmospheres 30°, at 15 atmospheres 25.4°, and at 25 atmospheres 16.7° per atmosphere: showing

that the increase of temperature during compression is greatest at low pressures.

The largely extended use of compressed air for engineering purposes has led to great improvements in air compressors, and responsible parties can now be found to furnish plant and guarantee results at a very moderate cost, thus removing any element of uncertainty. It is claimed that the best compressors now constructed give a result about midway between the isothermal and the adiabatic, and the net loss of power due to clearance is so small as to be practically unworthy of consideration.

The losses by transmission of air through pipes are comparatively slight. It has been stated by competent authority that there is not a properly designed compressed air installation to-day that loses over 5 per cent. by transmission alone. The largest compressed air power plant in America is that at the Chapin mines in Michigan, where the power is generated at the Quinnesec Falls, and transmitted 3 miles. The loss of pressure as shown by the gauge is only 2 pounds. At the Jeddo Tunnel near Hazelton, air under 60 pounds pressure was conveyed 860 feet, and the gauges indicated no difference of pressure. The pipe in this case being 5¾ inches in diameter, was very large for the quantity of air used.

The losses in compressed air, it is said, may be reduced to 20 per cent. of the power used by combining the best system of reheating with the best air compressors.

In France, England, and Germany there have been erected during recent years large compressed air installations. In Paris about 25,000 horse-power is transmitted over the city, and is used to drive engines and

for many other purposes. A small motor 4 miles from the central station can indicate in round numbers 10 H. P. for 20 H. P. at the station itself, and by combining the American Compound Condensing Corliss Air Compressor with an efficient and economical reheating apparatus, and Corliss or other economical engines, an increase of efficiency of 50 per cent. may reasonably be expected.

The air used in Paris is about 11 cubic feet of free air per minute per indicated horse-power. The ordinary practice in America with cold air is from 15 to 25 cubic feet per minute per indicated H. P. The engines in France were found to consume about 15 cubic feet of air per minute per H. P. without reheating.

The amount of coal consumed in Paris during reheating is trifling. With the reheaters commonly employed, it amounts to from one to two cents per horse-power per day, and these figures, it is said, can be reduced considerably by a more economical system of reheating.

In the transmission of air through pipes, the loss of pressure can be very conveniently and accurately calculated by taking the loss for a given length and diameter of pipe and initial velocity, and determining the loss for any other velocity, diameter, and length, by a simple proportion, observing that the loss of pressure is—

Directly as the length of pipe and square of the initial velocity.

The friction in 1 mile of 6-inch pipe, with an initial velocity of 20 feet per second, is 5.1 pounds per square inch.

Suppose 1500 cubic feet of free air per minute, under 500 pounds pressure or 34 atmospheres, are to be carried 1 mile. What will be the loss by friction?

In this case, the initial volume will be $\frac{1500}{34} = 44$ cubic feet. 44 cubic feet per minute = 0.74 cubic foot per second.

A pipe 6 inches in diameter has an area in square feet of 0.127.

$0.74 \div 0.127 = 6$ feet per second, nearly.

Then $5.1 \times \frac{6^2}{20^2} = 0.457$ pound, a very inconsiderable loss in a distance of 1 mile, and the loss in 10 miles would be only $4\frac{1}{2}$ pounds.

In this calculation the initial density of the air is not taken into consideration, and it does not affect the result with an elastic fluid of uniform density; but a general formula, applicable to all elastic fluids, must recognize density, and the loss of pressure in elastic fluids of different densities, other conditions the same, will be directly as the densities. The loss of pressure, for example, in the transmission of steam through pipes will be about half as great as with air, other conditions, except density, being the same.

The cost of hydraulic pipes to resist high pressures has, January, 1893, been obtained from manufacturers.

	Cents.
3-inch pipe per lineal foot	20.82
$3\frac{1}{2}$ " " " "	24.61
4 " " " "	29.26
$4\frac{1}{2}$ " " " "	35.25
5 " " " "	43.51
6 " " " "	54.87
7 " " " "	64.84
8 " " " "	84.90
9 " " " "	115.78

The quantity of air required for running an ordinary street motor of about 18 or 20 horse-power capacity, for a distance of 1 mile upon an ordinary street railway, has been positively and accurately determined by several months' service of the Hardie Motor on the Second Avenue Railroad in New York in 1879, and also by the experience in France and England. On this important point there can be no mistake, and ample evidence can be furnished.

The Hardie combined motor and car, weighing $8\frac{1}{2}$ tons, including passengers, ran $9\frac{3}{4}$ miles on a bad track on the Second Avenue Railroad. The pressure at starting was 360 pounds; at finish, 100 pounds and reservoir capacity 160 cubic feet, giving the quantity of free air at atmospheric pressure expended 2.773 cubic feet = 284 cubic feet per motor-mile, or $33\frac{1}{2}$ cubic feet per ton-mile.

The Mekarski (French) combined motor and car, weighing 8 tons, including passengers, ran $7\frac{3}{4}$ miles on a street tramway with an expenditure of $36\frac{1}{2}$ cubic feet per ton per mile, or 292 cubic feet per car-mile.

The Beaumont (English) locomotive, weighing 7 tons, is claimed by the inventor to be capable of drawing a 5-ton car 10 miles on a street tramway. Capacity of reservoir, 100 cubic feet. Pressure at starting, 1000 pounds per square inch; at finish, not stated, but presumably 80 pounds. This gives a total expenditure of 6.100 cubic feet of free air, or 50 cubic feet per ton per mile, or 500 cubic feet per train-mile of motor and car.

The Beaumont locomotive, of same capacity and pressure, but said to be 10 tons, ran 15 miles light,

and without stopping, on a clean steam railway, using 6.100 cubic feet of free air, or 40 cubic feet per ton per mile.

The Scott-Moncrieff combined motor and car, weighing $7\frac{1}{2}$ tons, is claimed to have run 7 miles on a street tramway. Reservoir capacity, 150 cubic feet. Pressure at starting, 390 pounds (26 atmospheres); at finish, not stated, but presumably about 50 pounds, thus using 3450 cubic feet, or $67\frac{1}{2}$ cubic feet per ton per mile, 472 cubic feet per car-mile.

It is thus seen that Hardie and Mekarski produce the best results, owing to the more efficient method of heating. Beaumont heats a little, and Scott-Moncrieff not at all.

It thus appears from all these statements that the Hardie motor gave better results than any other, although the mechanical work was defective owing to cheap construction without the usual facilities for locomotive work, and the runs were over a very bad track. It is certain therefore that a consumption of 300 cubic feet of free air used in the cylinders at a pressure of 56 pounds per square inch will suffice to run the motor one mile.

The reservoir in the Hardie motor had a capacity of 160 cubic feet; but even at 130 cubic feet, and a pressure of 34 atmospheres, 500 lbs. per square inch, the motor could run 12 miles and retain over 60 lbs. pressure at the end of the trip.

The Hardie motor when towing two cars used 480 cubic feet of air per mile.

It has been found that whatever may be the pressure of air in the motor tanks beyond a certain very moderate excess above the working pressure, the additional

power expended in compression cannot be made available in propulsion, but is lost in wire drawing the air through the reducing valve to a lower pressure. Consequently all the power expended to secure high pressures in the reservoirs serves only to increase the tank capacity and the length of run.

To avoid this loss, compound engines have been tried, but they are not only unsuited for small motors in consequence of complication, but they have failed to accomplish the object.

Another plan of utilizing the high pressure has been proposed by allowing it to escape through an injector, and thus forcing an additional volume of fresh air into the motor cylinders, reducing to that extent the draft upon the reservoir. It is not known that this plan has been tried, or, if tried, what has been the percentage of gain.

It is, therefore, an interesting question to determine what is the actual loss in high compression measured by coal consumption per mile run.

Assume as data, therefore, that a motor reservoir of 130 cubic feet capacity is to be charged once in two minutes to a pressure of 500 pounds, and determine the value of the coal consumed in raising the pressure from 250 to 500 lbs. per square inch, which coal consumption cannot be again reproduced in work, but represents a loss.

To obtain 130 cubic feet at 500 lbs. or 34 atmospheres, 260 cubic feet at 17 atmospheres must be reduced in volume one-half in two minutes of time. In effecting this compression a piston with an area of one square foot, or 144 square inches, must travel 130 feet in two

minutes, with a pressure at the start of 250 pounds per square inch, at the end of 500 pounds and mean of $0.846 \times 500 = 423$ lbs.

The amount of work done in one minute is $423 \times 144 \times \frac{130}{2} = 3,959,280$ foot-pounds per minute = 120 horse-power.

At $2\frac{1}{2}$ pounds of coal per horse-power per hour, the consumption in 2 minutes for 120 horse-power would be 10 pounds, and as this volume of air at 500 pounds will run the motor 12 miles, with a reserve in the tank at the end of the trip of 20 per cent., the actual consumption for the trip of the coal required for double compression would be but 8 pounds, costing, at $3 per ton for the cheap coal used, $1\frac{1}{2}$ mills per pound, or 12 mills for 12 miles, or one mill per mile run of motor.

It appears, therefore, that notwithstanding the fact that high pressures cannot be directly utilized in propulsion, the cost of producing them is so small, and the advantage of increased storage capacity and increased length of run so great, that it secures great economy to use them, and it is useless to attempt to employ cumbersome mechanical devices to save so inconsiderable a loss, even if there was a prospect of success, which there is not.

If air at 500 pounds could be applied directly to the piston of the motor-cylinders, and cut off at one-sixteenth of the stroke, the weight of air, or the quantity at atmospheric tension, would be the same as if used at 250 pounds and cut off at one-eighth; but there would be a considerable difference in the work done, as will be seen.

The initial pressure being unity, the average at $\frac{1}{16}$ is 0.236.

The initial pressure being unity, the average at $\frac{1}{8}$ is 0.355.

Then, $500 \times 0.236 = 1.180$.

And, $250 \times 0.355 = 0.888$.

These figures are in proportion to work done, and the difference is 0.292, or 32 per cent. in favor of the higher pressure if it could be utilized.

But the important practical question is: What does this difference cost in money measured by coal consumed? The data are, air per mile 300 cubic feet, 12 miles = 3600 cubic feet. Two-minute intervals = 1800 cubic feet per minute. To compress this volume requires 500 horse-power per hour, or $500 \times 2\frac{1}{2} = 1250$ lbs. coal per hour. 42 pounds in 2 minutes for a run of 12 mills = $5\frac{1}{4}$ mills per mile, and the loss by wire draw 1.31 mills per mile.

But by having 500 pounds pressure in the reservoir instead of 250, the motor can run 12 miles instead of 6, and the cost of compression from 250 pounds to 500 pounds is only one mill per mile, as shown elsewhere: therefore it is great economy to use high pressure, even if there is a loss at the reducing valve.

It may be interesting to give this subject further consideration, and in this connection a quotation from the pamphlet of Mr. Potter becomes pertinent as an introduction. Referring to losses, he remarks:—

By far the greatest loss of all is accounted for by the "wire drawing," which takes place in reducing the storage pressure to a practicable working pressure.

Let it be supposed, for illustration, that this storage

pressure is 1000 pounds to the square inch, and that it is reduced to 100 pounds in the locomotive cylinders. It may easily be computed by experts that there will be a loss in this case of over two-thirds of the power originally contained in the air in its high pressure state. Experiments have been made with a view to recovering this loss by direct expansion in the locomotive cylinders, but they have utterly failed, as will now be made apparent.

It seems reasonable and rational to suppose that this would be the proper way to overcome the difficulty, provided that it did not entail too much complication of machinery, and it was accordingly in this manner that Hardie originally attempted it.

Discarding the idea of compounding the cylinders as impracticable, owing to the complication necessarily involved, and other considerations, which will be referred to further on, he designed an experimental engine having two cylinders of equal dimensions and slide-valves as usual, adding cut-off valves and other simple devices which experience had shown to be essential to the economical use of compressed air. The slide-valves were specially designed to balance the high pressure, all parts were proportioned to bear the excessive strains, and the lowest possible storage pressure for the air adopted (360 lbs. per square inch). Upon trial this engine, which was in the form of a combined motor and car, was found to work exceedingly well, running ten miles on a street tramway with one charge of air.

Indicated diagrams, taken at all initial pressures, showed the most beautiful and perfect expansion curves; and indeed, the experiment was regarded as eminently

satisfactory. Mr. Hardie, however, being curious to know how much greater was the efficiency by this method than by the use of a reducing valve, had one applied, and found to his great astonishment that the engine worked just as well; that is to say, that it ran as great a distance as before. The engine was carefully examined, but no defects were found, and the experiments were repeated with the same results. Experts were consulted to ascertain, if possible, the reason, and the only conclusion arrived at was that possibly the use of such high pressures in the engine cylinders entailed loss by excessive friction and leakage, which in practice neutralized the theoretical gain. Be that as it may, there was no disputing the facts, and Mr. Hardie, therefore, gave it up and adopted the reducing valve, there being no advantage in straining the machinery with high pressures.

It appears that Colonel Beaumont, in England, has been laboring diligently to effect the same object by compounding the engine cylinders; but as will be seen, his experiments led to the same practical conclusions as those of Mr. Hardie. He begins by presuming that the energy stored in the high pressure air is all, or nearly all, recoverable by expansion in the motor cylinders, and hence argues that the only consideration in fixing the initial pressure is that of conveniently storing the amount of power in a given space. This, he says, is 100 lbs. per square inch in a 7-ton motor having a capacity of 100 cubic feet and of hauling a 5-ton car 10 miles on a street tramway.

Here follows a statement of the practical disadvan-

tage of using compound cylinders upon a street motor which it is not necessary for present purposes to repeat.

Proceeding to investigate the results of the experiment obtained by Beaumont with such an engine, reference is made to a paper read by him on the subject before the Society of Arts and published in the journal of the Society March 18, 1881. On page 389 there is a tabular statement of experimental data, which is here reproduced.

Table of Experimental Data.

Air Pressure.				Minutes.			Pounds.
925 lbs.	run	1000 yards	in	9	reduced	pressure to	805
805	"	"	"	9	"	"	730
730	"	"	"	9	"	"	660
660	"	"	"	13	"	"	595
595	"	"	"	10	"	"	520
5000 yards run. Loss 405 lbs. in 50 minutes = 3 miles 73 yards per hour.							
520 lbs.	run	1000 yards	in	10	reduced	pressure to	435
435	"	"	"	10	"	"	360
360	"	"	"	10	"	"	288
288	"	"	"	10	"	"	205
4000 yards run. Loss 315 lbs.							

If instead of expanding this air freely, it were made to do useful work, from 1000 lbs. down to 200 lbs., and then from 200 lbs. to atmospheric pressure, the work done, upon the whole, would reasonably be expected to be greater than in the latter case alone. Hence, Beaumont's claim to having accomplished great results is readily believed, both by practical and scientific men. That no such perfection is actually obtained in practice, however, will be seen from a careful study of the table. Here let it be observed the pressures are given at the beginning and end of each 1000 yards run,

the difference in each case being an exact measure of the quantity of air, and also, when the pressure is taken into account, a measure of the energy expended. Now let these differences be noted :—

First	1000 yards used	. . . . . .	120 lbs.
Second	"	"	75 "
Third	"	"	70 "
Fourth	"	"	65 "
Fifth	"	"	75 "
Sixth	"	"	85 "
Seventh	"	"	75 "
Eighth	"	"	72 "
Ninth	"	"	83 "

From what has been said it would have been expected that as more energy is stored in the higher pressures, these figures should have shown a gradual increase, until the last was about double the first. Neglecting the first as excessive and probably due to some special cause, it is seen that the remaining 8 trips were accomplished on practically the same quantity of air (viz. : an average of 75 lbs. to the square inch, or 5 volumes of the reservoir capacity at atmospheric pressure), but by no means on the same expenditure of energy ; and it is particularly noticeable that the eighth trip (or last but one) was accomplished on an expenditure which was less than the average. Hence the inevitable conclusion, that if the higher pressures had been reduced to the average pressure of the eighth trip, at least as good economy would have been attained, showing clearly that Colonel Beaumont's experiments go for nothing more than to confirm Mr. Hardie's experience, and that the advantages claimed for cylinder expansion beyond certain limits are mostly theoretical.

VII.

TESTS OF THE HARDIE COMPRESSED AIR MOTOR.

In 1879 the writer was called upon to investigate and report, as consulting engineer, upon the practicability and relative economy of compressed air as a motive power upon street railways.

At that time five motors had been constructed for the Pneumatic Tramway Engine Company and were in daily use upon the Second Avenue Railroad in New York, by consent of its officers, but at the expense of the Pneumatic Tramway Company, which desired an opportunity of giving the invention a practical test.

The motors were constructed upon plans prepared by Mr. Robert Hardie, a Scotch engineer of remarkable ability, who had been engaged with Scott Moncrieff, of Glasgow, in very successful experiments in that city. Lewis Mekarski, of Paris, had also made successful experiments in the same direction.

The motors and also the compressor plant were constructed at the Delamater Works in New York, but as this establishment did not make a specialty of locomotives and had not at that time the appliances that were necessary to secure the best results, some of the wearing parts were found to be rather soft, a fact which to some extent increased the cost of repairs, but did not discredit the plans of construction. There can, of course, be no more wear on the rubbing surfaces of a pneumatic motor,

when properly case-hardened, than on an ordinary locomotive.

The consideration of the applicability of compressed air as a motive power for street engines was taken up with no bias in its favor, and the following extracts from the report, made February 20, 1879, will give the conclusions reached after careful investigation of the motors in actual daily use.

In 1856, while engaged in devising plans for the construction of the Hoosac Tunnel, the writer had, after careful consideration, rejected compressed air, and decided in favor of steam in connection with a vacuum system of ventilation, as more simple, economical, and effectual under the conditions then and there existing in regard to its use, limited financial resources for the purchase of plant being an important consideration.

In any mode of compressing air in which the direct pressure of steam is employed, as in reciprocating pumps, a cylinder of steam unexpanded and at maximum pressure must be expended to secure under high tensions a small fraction of a cylinder of air at the same tension.

If a number of small compressors be connected with one shaft by cranks, at such angles as to divide the circumference equally, the loss of power would be reduced, or the percentage of useful effect would be increased.

Suppose, for the sake of illustration, that there were ten compressors connected with one shaft, and that it was proposed to compress the air to ten atmospheres. There would be ten discharges into the receiver at each revolution, each discharge being one-tenth of a cylinder,

and the sum of the whole equal to one full cylinder at the proposed maximum tension.

The power exerted in effecting the compression in each cylinder would be in proportion to the mean pressure throughout the stroke, if the air cut off at one-tenth were allowed to expand, which is 3.302; and if the air was not used expansively the theoretical loss without allowance for friction would be as 3.3 to 1, and with friction fully as 5 to 1.

But the air can be and is used expansively, and the simple device of a fly-wheel, by which momentum can be stored up and maintain uniformity during a revolution, secures equally favorable results with a small as with a large number of compressors connected with a shaft. There is no reason whatever to question the results claimed for the compressors manufactured at the Delamater works, and used on the Second Avenue Railroad, of 50 horse-power of compressed air, capable of being fully utilized for every 100 horse-power expended in the engine which works the compressors.

But it will be said there is still a loss of one-half as compared with steam applied directly. The answer is, not in cost of power; and in this fact is found the key to the solution of the problem.

The minimum of weight is essential in a locomotive engine. Heavy apparatus for securing economy of fuel cannot by any possibility be applied to it. Compound and condensing engines are entirely inadmissible on wheels of small motors adapted to street service, but all the known economies in engines, regardless of weight, can be introduced in stationary plant, and Corliss, Dela-

mater and others, now secure as an ordinary result a duty of one horse-power from 2½ pounds of coal.

At the Holly Works at Lockport, which claim an exceptionally high average duty, the daily evaporation is nine pounds of water to one pound of coal under 25 pounds pressure, or seven pounds of coal to one cubic foot of water evaporated; and in small boilers, such as are used for heating purposes, the average evaporation under ten pounds pressure is only four pounds of water per one pound of coal, or 15.7 pounds of coal per cubic foot of water evaporated.

With no very reliable data to determine the consumption of coal and evaporation of water in ordinary street motors, it will, no doubt, be greatly in their favor to credit them with developing a horse-power with ten pounds of coal; and the conclusion, therefore, is that although one-half the power of the stationary engine is lost in compressing air, yet the economy of fuel can be made so great that a given amount of power in compressed air is secured at one-half the cost of the direct application of steam to street motors.

But this is not all. By the simple device of heating the air by passing it through a tank of water, it has been clearly demonstrated as the result of constant practice in Paris, confirmed by recent experiments on the Second Avenue Railroad, that capacity for work is doubled, or the gain 100 per cent., making the economy of power as compared with the direct application of steam to street motors, measured as it should be, by coal consumed, four to one in favor of compressed air.

Air is compressed into the car reservoirs under a pres-

sure of 350 pounds per square inch, or 24 atmospheres, nearly.

It is not applied directly to the motor cylinders at this pressure, experience having shown that the best practical results are secured at 16 atmospheres, about 240 pounds.

But the air is not applied cold; it is admitted to a tank of water placed on the front platform of the car, containing 5 cubic feet of water, drawn from a stationary boiler, under 80 pounds pressure and having a temperature of 328°.

If air is admitted to the tank at 60°, and leaves it at 328°, the increase of temperature will be (328—60) 268°.

To raise one pound of water from 32° to 212°, or 180°, requires as much heat as would raise 4.27 pounds of air through the same range. The specific heat of air as compared with water being as 0.2377 to 1, one pound of air increases in volume by heat from 12.387 cubic feet at 32° to 19.323 cubic feet at 328°=6.936 cubic feet increase.

The volume of air at 24 atmospheres being 1, the volume at 16 atmospheres would be 1.5. If the volume of air at 32° be 1, the volume at 60° will be 1.061, and at 328°=1.59. It appears, therefore, that in heating a given quantity of dry air to 328°, it will be increased in volume under constant pressure over 50 per cent.

This expansion is due simply to *dry* air; when moisture is present to the point of saturation the pressures are greatly increased.

If the air at 30° be taken as unity, dry air at 212°

will occupy a volume of 1.375, and saturated air at the same temperature 2.672, or about double.

Conceding that only a small part of the theoretical expansion can be realized in practice, as the air when expanded in the motor cylinders is cooled very rapidly and there are other losses, there is still a wide margin to justify the claim of double power from heating the air. This declaration was fully sustained by actual work on the Second Avenue Railroad, where double runs of 6½ miles had been accomplished with the same expenditure of moist and heated air as single runs of 3¼ miles with dry air. The inevitable conclusion that results therefrom is that the power secured and utilized in air compressed with the best engines and compressors now in use costs, as compared with ordinary steam street motors, only one-fourth as much per horse-power measured by the coal actually consumed.

The air is not admitted to the motor cylinder at 350 pounds pressure, but at a much lower pressure, so that after passing the tanks and becoming heated and charged with vapor, it enters the cylinders at 250 pounds, requiring but a comparatively small volume of the dry air from the reservoirs to do the work.

This uniformity of pressure is secured by means of a reducing valve placed in the pipe, which acts automatically until the pressure is reduced below the pressure of admission. When the air has become so exhausted as to fall below this pressure, the reducing valve remains fully open.

If the water should be cooled down 100 degrees, the power of the heated air would be reduced, but would still retain great efficiency.

It can, therefore, readily be understood that a very important gain results from heating the air, and the economy of the arrangement is so great that it should never be omitted. The use of a small petroleum lamp to retain a high temperature in the water would add to the efficiency.

Cost of Heating the Air per Mile.

To raise 5 cubic feet of water from 212° to 328° requires, as we have seen, 36,192 units, or 1251 units per mile. Allowing 8000 nnits of heat per pound of coal consumed, the coal required to heat the 5 cubic feet of water would be 36,192 8000 = 4.5 pounds, at a cost of one cent, and this is less than average duty.

It would seem from the result of this calculation that fully 100 per cent. had been added to the power of the engine and to the miles run, at a cost of one cent in coal for heating the water.

How many Miles will the Pneumatic Motor Run?

The air reservoirs contain 160 cubic feet at 24 atmospheres. The equivalent at one atmosphere is 3840 cubic feet. Allowing one-third to be retained as reserve, there will be left to be utilized 2560 cubic feet. But in consequence of vapor and expansion by heat, this quantity is practically equivalent to 5120 cubic feet at the escaping tension. The number of cubic feet of air and vapor expended per mile run has already been ascertained to

be 720 cubic feet; and 5120 ÷ 720 = 7.1 miles nearly, still leaving a reserve of one-third.

But it has been found that the actual performance exceeds this theoretical limit, and that starting with 350 pounds pressure, 9¾ miles have been run with a reserve of 85 pounds. How can this be accounted for? Simply by the fact that the estimate of 7.1 miles was based on the supposition that a cylinder of mixed air and vapor at atmospheric tension was expended at each stroke. If nearly 50 per cent. more duty was actually secured, it proves that *less* than a cylinder of air and vapor did the work.

But, it may be asked, How is this possible? How can expansion be carried beyond atmospheric tension without creating a vacuum, and losing power by working against back pressure? This question was asked of Mr. Hardie, and the explanation brought to light another beautiful feature of this motor. There are valves called suction-valves in the exhaust passages, and whenever the tension of air in the cylinder falls below that of the atmosphere, these valves open and permit the stroke to be completed without back pressure, so that it is not necessary to use more air than will overcome the resistances, and this may vary from a full cylinder to a very small fraction, or between limits as extreme as one to thirty.

Increased Power from Motor Cylinders Acting as Air Pumps.

The motor cylinders are so arranged that in descending steep grades they act as air pumps, and at the same

time as brakes, by which means it is found, as stated by the company's engineer, Mr. Hardie, that in running down grade on the Second Avenue Railroad, pumping back against a pressure of 200 pounds in the receiver, the pressure was increased 7 pounds in a distance of 0.4 mile. As it requires 360 cubic feet to run one mile, 0.4 mile would require 144 cubic feet.

If the pressure were increased 7 pounds in a receiver containing 160 cubic feet at 200 pounds, the air pumped back would have been 5.3 cubic feet at 200 pounds in 0.4 of a mile, equal to 69 cubic feet at atmospheric tension, which is about half the amount of air that would have been expended in running an equal distance with the aid of the heat on a level, with a consumption of one cylinder of air at each stroke, but with actual results 50 per cent. greater.

To appreciate the importance of this result, it must be observed that not only is all the air saved in running down hill and not a particle used, but half as much or more as would have been expended with the aid of heat and vapor upon a level is pumped back again, and at the same time the action of pumping back acts as a most efficient brake, the efficacy of which is spoken of by the intelligent mechanical engineer of the Delamater Works in terms of the highest commendation.

This is certainly a most extraordinary result, and so large a percentage of gain is only possible in consequence of the great expansion in the motor cylinders. The air and vapor escape at the tension of the atmosphere, without the noise which attends the escape of high-pressure steam. When the air at atmospheric tension is pumped back again, it can readily be perceived that a

certain percentage of the power expended will be restored, since only half a cylinder of air or less is required to do the work at each stroke.

Such a contrivance can only be characterized as admirable, and, it will be perceived, adds another considerable percentage to gain in coal as compared with steam motors.

When a locomotive engine shall, while running, be able to manufacture coal and store it in the tender, it will then be able to rival this performance of the pneumatic motor.

It has been shown that at atmospheric tension the contents of the motor cylinder are just one cubic foot for each revolution of the car wheels and that there are 720 revolutions per mile. There should be pumped back therefore 720 cubic feet if the inclination were steep enough to employ full power, which is found by computation to be 198 feet per mile, and when heated, saturated, and expanded, this air should run the car two miles or more, instead of one. In other words, while running down hill one mile, on a grade of 198 feet, the motor theoretically might store up enough to run it two miles on a level; and recent experiments have shown that 50 per cent. may be added to this estimate.

Heat and Cold by Compression and Expansion.

In some forms of pneumatic apparatus much inconvenience has been experienced from the heat liberated in compression, and again from the intense cold resulting from expansion, which deposited ice in the cylinders and ports when moisture was present, as it always is in air

in its ordinary condition. It has been stated by writers on pneumatics that one pound of air at one atmosphere and at 60° compressed to two atmospheres is heated 116°, and the units of heat liberated per pound are $0.238 \times 116 = 27.6$ units.

Conversely the expansion of air causes an absorption of heat or production of cold to a corresponding extent.

The compressors constructed at the Delamater Works, in New York, secure comparative exemption from the inconvenience both of heat and cold. The apparatus now in actual use on the Second Avenue Railroad consists of an engine with two steam cylinders 12 inches diameter and 36 inches stroke, operating two double-acting compressors of same stroke, one of which has a diameter of 13 inches and the other a diameter of 6½ inches.

The number of strokes per minute in charging a car are 76 at the commencement, and 70 at the end; the difference being caused by the difference in work to be performed.

The fly-wheel weighs about 4 tons, with a diameter of about 10 feet.

The air cylinders are jacketed, and a current of cold water circulates around them continually.

The air compressed in the first compressor to about 5 atmospheres, passes into a tank of water in which the water is kept cool, and thence into the second compressor, where it is reduced in volume one-fifth a second time, making one-twenty-fifth of its original volume.

The water-tanks perform a most important office, not only in cooling the air, but in drying it also.

The explanation of this apparent inconsistency is simple.

Ordinary atmospheric air contains more or less water, which on reduction of temperature below the dew-point is deposited to a certain extent on cold surfaces.

In compressing 25 cubic feet of air into one, and cooling it with water, it is estimated that twenty-four parts out of twenty-five of the water will be absorbed and removed.

When this dry air is again expanded by being utilized in the motor, it cannot deposit ice, because there is so little contained water to form ice, and hence the fact, which it is said has excited great surprise amongst observers, that no frost whatever was formed except on the outside of the pipe from the condensation of outside moisture.

Mr. Hardie stated that when the pressure ran low and the temperature of the tanks fell below 100° frost began to be formed. This is precisely as should be expected. If air, in being compressed to one-half its volume, liberates 116 degrees of heat, it must absorb an equal amount in expanding, and if the water has cooled so low as not to furnish sufficient heat to compensate for it, the moisture taken from the water-tank must form frost to some extent.

A suggestion may here be offered in regard to the future possibilities of compressed air. Why can it not be compressed to high tensions by cheap power, transmitted for considerable distances through pipes, and used expansively in compound engines with heater, without the annoyance and risk of large boilers and coal consumption on the premises where the power is utilized? There

is no reason to apprehend danger from this increase of pressure. The air receivers, unlike steam boilers, never deteriorate; the air being perfectly dry, and the receivers coated internally, there can be no rust: and if pressure is increased, the thickness of material can be increased also, and the factor of safety remain the same. Any defect of material or workmanship would be revealed by proper tests; and if a rupture should occur, there would be only an escape of cold air—no steam and no fragments of iron. A cylinder, fully charged, was ruptured in France purposely by the fall of a heavy weight. The air escaped simply with a hissing sound; no fragments were projected as in explosions of steam boilers, and cold, not heat, resulted from the expansion.*

What Grades can the Pneumatic Motor Overcome, and What Loads can it Carry?

These are pertinent questions, and can be readily answered. Ordinary locomotives are so proportioned in their boiler and cylinder capacity as to be able to slip their wheels on a dry rail if the engine should be chained fast, so that it could not advance upon the track.

In that case the adhesion, which is, at a maximum, about one-fifth of the weight upon the drivers, measures the power of the engine, and not the pressure in the cylinders. The power varies, and is greatly reduced in bad conditions of the track.

Power of Motor Cylinders.—Assume that the air is used under 16 atmospheres, cut off at one-sixteenth, and

* This was written in 1879. At the present time, 1893, more than 25,000 horse-power are employed in this way in Paris alone.

expanded to fill a cylinder at atmospheric tension, giving mean pressure at 0.236. The initial pressure being 16 atmospheres, the mean pressure is $16 \times 0.236 = 3.776$ atmospheres, and $3.776 \times 15 = 56.64$ pounds per square inch. The diameter being $6\frac{1}{2}$ inches, the area is 33.18, and the piston pressure $33.18 \times 56.64 = 1879$ pounds. If the air should be cut off at $\frac{1}{8}$, instead of $\frac{1}{16}$, the mean pressure would be 6.158, and the crank pressure 3064.

There are 2 cylinders, cranks at right angles, one at full stroke when the other is on its centre. The weight of the car loaded is 8 tons. There are four wheels connected. Weight on drivers 16,000, adhesion one-fifth $= 3200$ pounds. The radius of the wheel is 14 inches, and of the crank $6\frac{1}{2}$ inches, then $3200 \times \frac{14}{6.5} = 6880$ pounds to be exerted on the crank, not allowing for friction of machinery, if it be required to slip the wheels on a dry rail. Or, stated in other terms, the power of 1879 pounds at the crank is equivalent to 871 at the rail, and 3064 at crank to 1422 at rail.

The power of the motor cylinders with ordinary consumption of air is therefore insufficient to slip the wheels on a dry rail, but with street motors so large an amount of cylinder power as would be required for that purpose is unnecessary; owing to the frequent bad condition of the track, a large surplus of adhesion is required. The cylinder power can be increased four-fold by admitting a full cylinder of air; but this would be objectionable, as causing waste of air and noise from exhaust, except in overcoming great resistances of short duration, as in pulling the motor over cobble-stones when derailed.

With a small motor of 6 tons the adhesion would be

reduced to 2400 lbs., and the crank pressure required to slip the wheels to 5160 lbs. The adhesion in ordinary conditions of the rail is therefore, as it should be, in excess of the cylinder power, and the wheels can slip only in consequence of ice and snow. It remains to determine the power for propulsion on a straight and level track and the power required on grades.

The traction of ordinary railroad trains is 9.2 pounds per ton on a straight and level road, based on the regular business of the Pennsylvania Railroad; but with a street motor it is said to require about 25 pounds per ton, eight tons require 200 pounds, and this resistance acting on a lever of 14 inches from the axle, while the propelling power acts with $6\frac{1}{2}$ inches, will increase the power on the crank to $200 \times \frac{14}{6.5} = 430$ pounds.

As the power on the crank with the 8 ton motor is 1879 lbs., it would be sufficient to move 4 such cars, or 32 tons, on a straight and level road, not allowing for friction of machinery and losses in transmission of power from the crank, if, as has been stated, the traction does not exceed 25 pounds per ton, upon which this estimate is based. It was found that when dry air was used and the machinery was cold, the pressure of the air by gauge indications being 20 lbs., it required the full head to propel the car, while, where warm air was used, the car moved when the gauge indicated considerably less pressure.

Twenty pounds pressure is $1\frac{1}{3}$ atmospheres. The average mean working pressure is 3.776 atmospheres. Twenty pounds produces 625 lbs. crank pressure, or 300 at rail, and if this amount was required to overcome friction and move the motor, it would be equivalent to

$37\frac{1}{2}$ pounds per ton, instead of 25 pounds, and absorb 50 per cent. more power than has been allowed; but it is stated that there was a back pressure at the time of several pounds per square inch, in consequence of the small size of the exhaust ports, which would cover a considerable part of this difference. It is possible, therefore, that, with the air heated, the traction may not exceed 25 pounds per ton; but it would be well to test both the traction of the motors and of ordinary cars by a dynamometer.

GRADES.

It has been shown that if air is admitted into the working cylinder at a pressure of 16 atmospheres, cut off at one-sixteenth of the stroke and expanded to atmospheric tension, the mean pressure on the crank would be 1879 pounds and the equivalent to overcome resistance at the rail 871 pounds, capable of moving on a straight and level road, if all could be utilized, 4 cars of 8 tons with traction of 25 pounds per ton, and certainly 2 cars.

Also if the air should be cut off at $\frac{1}{8}$, the mean crank pressure would be 3064 pounds and the equivalent at the rail 1422 pounds, capable of moving 4 such cars upon a level. As the angle of friction with traction of 25 lbs. per ton is 66 feet to the mile, the eight ton motor should be able to haul twice its own weight on a grade of 66 feet or 2 cars, on a grade of 132 feet 1 car; but 2 cars could be hauled by increasing the amount of air and cutting off say one-sixth, instead of one-eighth.

The eight ton motor without extra cars attached

should be able to overcome the steepest grades usually found on horse railroads. The steepest grade on the Second Avenue Railroad is said to be 230 feet to the mile, or one in twenty-three. The power with a full cylinder of air would be about 8 times the average power expended in working, and consequently the reserve is large enough to overcome great resistances of limited duration.

SMALL MOTORS OF 5 TONS WITH CARS ATTACHED.

It would be a most serious disadvantage if the general introduction of pneumatic motors should require the abandonment of the old plant. Fortunately such abandonment is not only unnecessary, but the best possible system for the economical operation of a line and for the accommodation of the public consists in the use of small motors, or of combination car and motor capable of carrying from one to three additional cars in a train under one conductor, at hours when the travel requires it.

Suburban residents desire frequently to make social visits or to attend lectures or places of amusement in the neighboring cities, and can testify to the discomfort, not to say danger, of riding home late at night with one foot on the platform and the other in space.

The ordinary horse car, loaded, weighs about five tons, the motor would weigh about the same, or with six tons would admit a large increase of reservoir capacity; there would then be no pretext for objection on the ground of injury to track. It could run with

one car in the middle of the day, and morning and evening with 2 or 3 under one conductor. It could make the trip in half the time, certainly in two-thirds, of the horse-car and take the place of horses, the sale of which would nearly or quite pay for the motor, so that there would be but little, if any, increase of capital for street motors, and nothing except for engines and compressors at the station.

The small motors, weighing 6 tons, would have the same cylinder power as the 8-ton motors previously described, which gives 871 or 1422 pounds at the rail, as the air is cut off at $\frac{1}{16}$ or $\frac{1}{8}$ of the stroke. The adhesion with dry rail is 2500 lbs., and the traction of the motor at 25 lbs. per ton $6 \times 25 = 150$ lbs.

If these small motors should be used to haul ordinary horse-cars, it becomes necessary, in estimating the performance of the motor, to know the traction of such cars. For obvious reasons this traction must be less per ton than that of the motor, and yet more than that of ordinary railroad cars, which is 9 pounds per ton. Probably 15 pounds per ton would be a full allowance for the traction of ordinary horse railroad cars, and a train of one 6-ton motor and two ordinary cars of 5 tons each, loaded, would make the weight of the train 16 tons, and the traction 300 pounds—an average for the train of 18.8 pounds per ton. And 18.8 pounds per ton traction would give the angle of friction at which the train would descend by gravity $= 44\frac{1}{2}$ feet to the mile.

The train of one small motor and two cars could ascend grades of 178 feet to the mile, and with one car

grades of 240 feet to the mile, and steeper grades could be overcome by using more air.*

The separate motor, not intended to carry passengers, except, perhaps, on top, would permit an increase of reservoir capacity from 160 to 225 cubic feet; and if reservoirs be placed also under the seats of each car, the capacity of a two-car train with motor would be extended to 325 cubic feet, or doubled, and the run to 12 miles. If, in addition, in speculating upon the possibilities of the future, the reservoir pressure should be increased to 500 pounds, instead of 350, the run would be extended 43 per cent., or to 17 miles, and with one car attached to motor instead of two, still further. For working elevated railroads, as a substitute for steam, the pneumatic motor is the perfection of a propelling power. The motor itself could be filled with air reservoirs, giving, with the addition of reservoirs under the seats of the cars, almost unlimited capacity, and there is no run within suburban limits that would be beyond the power of the motor, with a single station in the middle of the road to reinforce the pressure. The cost of fuel would be reduced fully 66 per cent., and noise, dust, steam, and sparks from motor avoided.

If a motor should run off the track, it has power to run itself on the street pavements, and can be readily replaced by the aid of crowbars. If the machinery should become deranged, another motor could push it,

* Since the above was written further experiments have shown that the increased consumption of air by attaching horse-cars to the motor is about the amount that could be supplied by reservoirs under the seats, and, consequently, that the distance run need not be diminished by attaching additional cars if so provided.

and by a simple hose attachment the air in the disabled engine could work the machinery of the helper.

Horse-power of the Hardie Motor.

With cylinders on motor $6\frac{1}{2}$ inches diameter and 13 inches stroke, pressure of air 16 atmospheres, cut off at one sixteenth of stroke, giving average pressure 56.64 lbs. per square inch, and speed of motor six miles per hour, the horse-power applied to pistons will be found to be 17.7, or, if the speed is four miles per hour, 11.8 horse-power.

Area of piston 33.18 square inches. Travel of each piston 22 inches to each revolution. 720 revolutions per mile = 3120 feet for both pistons per mile.

$3120 \times 33.18 \times 56.64 = 5{,}862{,}480$ foot-pounds per mile = 586,248 foot-pounds per minute, and $586{,}248 \div 33{,}000 = 17.7$ horse-power.

This assumes that the air operates upon the piston to the full limit of the stroke, but with less resistance much less air is used, and the horse-power will be reduced; on the other hand, there may be occasions when a temporary increase becomes necessary. By letting in a full pressure of air more than three times the normal pressure can be applied immediately.

A few minor points in favor of the motor will be stated. Skilled engineers are not required to run them; a man of ordinary intelligence can learn to run these motors in a single trip. What is a most remarkable and beautiful feature of the contrivance is that a driver, however ignorant or careless he may be, cannot fail to use exactly the proper amount of air for the resistance

to be overcome, and cannot waste it. If he admits too little, the car slackens speed or stops; if too much, he must apply the brake. All is done by the movement of a lever, back or forward; no other brake is needed, and the motion of the car is a perfect governor.

Another advantage of the motors is that the view of the track is unobstructed and can be seen from the platform on which the driver sits, while horses obstruct the view of the track for 30 feet.

On a level track the car can be stopped within its length when running at a speed of 12 miles per hour, and on grades in a time longer or shorter in proportion. The brake can never be out of order so long as the car has the ability to move at all. The brake consists in a full or partial reversion by moving a lever.

If the lever should get out of order, which is scarcely within the bounds of possibility, the car could not move at all, therefore the brake cannot fail. It was noticed also in running along the Second Avenue Railroad on the motor that horses on the opposite track meeting the motor would sometimes shy, but other horses not on the track did not notice it. The car horses would, no doubt, soon become accustomed to the motor, but as its general use would supersede horses altogether, this fact is of little consequence.

OBJECTIONS.

A criticism of the motor has been made by a mechanical engineer of some prominence, which can only be accounted for on the supposition that the letter which recites the objections was written without consideration.

It is desirable, however, to have objections stated; when they can be shown to be groundless they serve to inspire and increase confidence.

The objections were:

1. The air car requires 50 horse-power in compressors to keep it in operation.

True! But if dry air be used the same engine will charge 7 cars per hour, and if moist and heated air be used 14 cars, if the run should not be increased and only half the air should be required, which is only 4 horse-power to a car, and each horse-power costs in coal consumed one-fourth to one-third as much as in a street motor.

Second objection. The cost of repairs for the steam cars would be less than for the air car.

Ans. No reasons are given, and the fallacy of the assertion is self-evident. There is no fire-box to burn out, and no boiler to rust, burn out, or explode. The reservoirs, filled with air absolutely dry, are as nearly imperishable as anything on this mundane sphere can be. The parts liable to wear by friction are the same as on other engines, neither more nor less expensive to repair, but the heaviest expenses of fire-box, boilers, and flues are all saved.

Third objection. The air car is not so reliable as a steam car, as it has not the same surplus for emergencies.

Ans. Why not? A surplus is provided of 33 per cent. Does a locomotive finish its trip with as much reserve power in coal and water in its tender? Besides, all the cars of a train can have air cylinders under the seats, the whole of which can be held in reserve.

The above are the only objections advanced.

Location of Power Plant.

Considerations of economy would lead to the location of the power plant at or near the middle of the section of the road to be operated, for the reason that the power could be readily renewed by a simple hose attachment while passing the central station, whereas if located at one end a supply for a run of double the length would be required; but it may be, and in a majority of cases probably will be, found most economical to locate the compressed plant back of the main thoroughfare, where land is of comparatively little value, and transmit the compressed air through pipes to any number of reservoirs conveniently located along the route.

These reservoirs would occupy but little space, and would not require a front location upon the thoroughfare traversed by the cars. They could be placed one hundred feet or more in the rear, or even under ground, and from them strong wrought-iron pipes could lead to the track, where an air plug with hose attachments covered by a manhole plate would afford facilities for replenishing the air charge of the motors at any intervals however short that might be considered desirable. Underground pipes could be carried to the car sheds to supply motors with full charges while standing on the tracks.

As all the reservoirs upon the line would be connected with each other, and with the central plant the pressure would have a constant tendency to equalize itself throughout the whole system, and a large reservoir capacity thus created would be of great advantage in insuring an ample supply of air under nearly uniform pressure.

Oil is frequently transmitted in pipe lines under a

pressure of 1500 pounds per square inch, so that a pressure of even 600 pounds would not require pipes of extraordinary thickness.

In the transmission of elastic fluids through pipes for long distances there is a loss of power due to friction dependent upon the length and diameter of the pipe, but more upon the velocity of transmission. This subject was very fully investigated by the writer in 1879 in connection with the Holly system for the transmission of steam for heat and power.

If, for the present, it be assumed that air is compressed to 40 atmospheres at a central point, and transmitted by pipes of six inches diameter for utilization in distant reservoirs and in quantity sufficient to charge one car cylinder of 160 cubic feet capacity per minute, the initial velocity of the air in the pipe would be twelve feet per second as a maximum, and the loss of head by friction, based on the tables deduced from experiments at the Mt. Cenis Tunnel, would be but 1.83 pounds in a distance of one mile, assuming that the car cylinders should be returned entirely empty and require 160 cubic feet as the initial pressure.

But in the trips on the Second Avenue Railroad the cars returned to the station with one-third of their charge remaining, or with 8 atmospheres, after expending 16 atmospheres in the run; consequently a charge of 40 atmospheres would have permitted just double the distance to have been operated with a single charge, which would be 18 miles.

One car per minute could be required on any city line only at the hours of maximum business, and even at such hours, if the cars returned with partial charges, the

quantity of air required for re-charging would be less than the maximum, the velocity of transmission would be reduced, and the loss by friction, which is as the square of the velocity, would be reduced also. Instead of dispatching one car per minute, the same capacity can be more economically afforded by one motor car in 2 minutes with one trailer, and still more with 2 or 3.

It would seem to be practicable, therefore, on extended lines to locate compressor plants at intervals of 20 or 25 miles, and transmit power in pipes to intermediate stations 10 or 12 miles distant, with additional intermediate reservoirs at stated intervals to be used in case of accident, such reservoirs consisting simply of a number of small cylinders of steel two feet, more or less, in diameter, connected with each other by pipes. The cylinders of small diameter would be necessary to secure strength.

Whether the pneumatic system could be extended to supersede steam motors on ordinary railroads is a question that can be reserved for future consideration. It may be observed, however, that the traction on straight and level steam railroads is only 9 pounds per ton for the train, while on ordinary street railroads it has been estimated for the motor at 25 pounds. Also, that in passenger cars reservoirs of air cylinders can be placed below the seats, and the floor of the car may rest upon two longitudinal cylinders supporting in the middle of the car a number of transverse cylinders. The frame could be of hollow pipes, and thus a very considerable reservoir capacity could be provided in each car. A tender filled with air reservoirs could take the place of the ordinary tender with coal and water. How far such a train could be made to run with ordinary cars without

reinforcement of power, and what the cost of power as compared with steam, would be interesting inquiries, for the determination of which all the necessary data have not yet been fully presented, and it is moreover foreign to the present inquiry. There can be no doubt, however, and conclusive evidence can be and has been presented, that for street, elevated, and underground railroads steam cannot favorably compare with air, either in economy, convenience, or freedom from dirt, smoke, noise, and other nuisances. In fact, it can justly be claimed that it fulfils every condition that could possibly be desired, and is free from any objection that can be urged.

Record of Direct Experiments with the Hardie Motor.

For several days previous to March 12, 1879, experiments were made with the motor on the Second Avenue Railroad, the results of which it is proper to note.

March 9th, started from depot at 127th Street, and made three round trips, with the following record :—

1st trip started with pressure . . .	360	pounds.
Consumed	95	"
Returned with	265	"
2d trip started with	265	"
Consumed	95	"
Returned with	170	"
3d trip started with	170	"
Consumed	75	"
Returned with	95	"

This result was so remarkable, that the President of the Company, Mr. F. Henriques, requested the writer to superintend some further experiments, to ascertain if

increased duty would be secured by running at reduced pressures. Accordingly, on March 10th, three more trips were made, with the following record:—

1st trip started with	360 pounds.
Temperature of water	324°
Mean working pressure while running .	120 pounds.
Water absorbed	31 "
Pressure on return	290 "
Consumed	70 "
2d trip started with	286 pounds.
Mean working pressure . . .	120 "
Consumed water	11.3 "
Temperature of water on return . .	198°
Pressure at end of trip . . .	195 pounds.
Consumed	91 "
3d trip started with	195 pounds.
Mean working pressure until pressure fell below	120 "
Water absorbed	19.8 "
Temperature on return . . .	180°
Pressure at end of trip . . .	95 pounds.
Consumed	100 "

The comparison of these two tests exhibits very remarkable results.

The total consumption of air in the three round trips, starting with 360 pounds and finishing with 95, was 265 pounds, or an average of 88.33 each trip. The last trip of the first series was run with 75 pounds. This fact it is difficult to explain, as the water was certainly much cooler than at the start, and it could not have contributed so large a proportion of vapor.

In the first run of the second series the air consumed was 70 pounds pressure, equivalent to 747 cubic feet, or 57½ pounds at atmospheric tension, and this air absorbed the very extraordinary amount of 31 pounds of

water, or more than half a pound of water for each pound of air, which is double the average consumption and four times the capacity of ordinary air for moisture.

It will be observed, also, that a great reduction of temperature from 324° to 190° or 126° was found in the two runs.

The large quantity of vapor and heat abstracted from the water in the first run will fully and satisfactorily account for the small quantity of air consumed, and would serve to indicate the possibility of increasing the distance run by burning gas or petroleum to replace the heat which the air absorbs.

In the last run of the second series 100 pounds were consumed. This was to have been expected, as the water at the end of the run was 32° below the boiling-point, and water instead of steam was probably carried out.

On Tuesday, March 11th, further experiments were made to determine the effect of attaching additional cars to the motor. The following is the record taken by Mr. Harley :—

1st trip started from 127th street, with	300 pounds.
At depot, 97th Street, air pressure	250 "
Consumed in half trip	50 "
Coupled on 2 ordinary street cars, pressure at end of trip, 127th Street	170 "
Consumed with the 2 cars and motor	80 "
Temperature of water	205°
2d trip, started with	335 pounds.
Run at mean pressure	150 "
Cars in tow	2
Pressure at 97th Street	275 pounds.
Consumed	60 "
Water used	14.2 "
Reduced pressure in heater to	130 "

2d trip return, 2 cars in tow, started from 97th Street, pressure	275 pounds.
Pressure at 127th Street	190 "
Consumed pressure	85 "
Water used	14.2 "
3d trip, heated water again, 2 cars, started from 127th Street with a pressure of	330 pounds.
At 97th Street, pressure	265 "
Consumed	65 "
Water used	16 "
Return, no cars in tow, started from 97th Street	250 "
At 127th Street	200 "
Consumed	50 "
Water used	11 "

OBSERVATIONS.

It appears that the two *up* trips consumed 80 and 85 pounds of pressure, and the two *down* trips 60 and 65 pounds, and the up trips required 33 per cent. more than the down trips. This may be due to the very bad condition of the up track. The average round trip required 145 pounds with two cars attached to motor, as against 90 pounds with motor alone, an increase of 60 per cent., or 30 per cent. for each car hauled. The two cars probably weighed as much as the motor, and, if so, the traction of the cars would be 15 pounds per ton, assuming the motor at 25.

The data furnished by observations on the motor will serve to indicate the loss of power and of work in transmission from the piston to the rail. Starting at 350 pounds pressure, the run of 9¾ miles was made with 270 pounds pressure, or 90 pounds per average run, or 298 cubic feet of air, at atmospheric density, per mile. As-

suming for the present that the effect of heating and moistening the air is chiefly to compensate for the reduced temperature in expanding, and to secure the full benefit of isothermal expansion, the foot-pounds of work per mile will be computed on this basis.

The volume required per mile to fill the capacity of the working cylinders is 720 cubic feet; the 298 cubic feet therefore filling 40 per cent. of the cylinder capacity, leaving 60 per cent. to be replaced by air from the exhaust passages, by the opening of the suction valves.

If used under an average pressure of 170 pounds = 11.33 atmospheres indicated, or 12.33 atmospheres actual, the atmospheric pressure would be reached in $13 \times 0.4 = 5.2$ inches of stroke in cylinders, and the mean piston pressure during the 5.2-inch stroke would be 1732 pounds.

As there are 4 cylinder discharges to each revolution, and 720 revolutions to a mile, the travel of piston per mile run under pressure will be $720 \times 4 \times 5.2 = 14{,}976$ inches = 1250 feet, and $1250 \times 1732 = 2{,}165{,}000$ foot-pounds of work done at piston per mile of actual run. If now it requires a tractive force of 25 pounds per ton on a level road to move the motor, and the weight be 8 tons, then $8 \times 25 \times 5280 = 1{,}056{,}000$ foot-pounds per mile, which, if the road was level, would represent the actual work utilized from an expenditure of 2,165,000 foot-pounds upon the piston, which is 50 per cent. nearly.

It would appear, therefore, that only half the power applied to the piston is actually utilized in propulsion on the track, and the balance must be expended in overcoming friction of motor and other resistances and

losses. The power required to move the motor, if applied externally, and also the traction of the ordinary horse-cars, is not known, and should be determined.

The computation of average run has been based on an expansion of 12, and reaching atmospheric tension at 0.4 of the length of the cylinder, using only one-thirtieth part of a cylinder of air at each stroke. If a full cylinder of air should be used, the power on the piston would be increased nearly nine times, but the consumption of air thirty times.

This great reserve of power over the average for ordinary work is an advantage of no small importance. The reserve of power can be drawn upon to overcome great resistances, if of short duration.

As an illustration of this fact, and since the above paragraph was written, Mr. James, who was associate engineer with Mr. Hardie, states that on one occasion the motor got off the track at a sharp curve and switch at the 127th Street depot; a ditch had been dug for gas pipes and filled in, but not paved. The hind wheels sunk in the ditch until the frame of the motor rested on the pavement. A high pressure was let on and the machine pulled itself out without further assistance.

This power of overcoming great resistances of short duration is of great value.

In the consideration of the question of hot water motors, the position was taken that in the conversion of hot water into vapor or steam nearly a thousand degrees became latent, and this latent heat so rapidly cooled the remaining water from which it was abstracted that it was not possible, without the use of a fire, to restore the

heat, and that the motor could not possibly run the distance claimed for it.

The observations just reported on the Hardie motor fully sustain these conclusions.

The first trip in the second series started with full tank, 5 cubic feet or 310 pounds of water, at a temperature of 324°, and used 31 lbs. water.

The second run used 11.3 lbs., and the third 19.8 lbs., in all 62.1 lbs., and the temperature in return was 180° with 248 pounds of water.

The differences there were :—

310 pounds water at 324°	=	100,440	units.
248 " " 180°	=	44,640	"
Units lost with 62 lbs.		55,800	

But 62 lbs. water with a difference of temperature of 144° would remove only 8928 units, leaving 46,972 units to be accounted for as latent heat. This is equivalent to 758 units per pound of water evaporated.

As this is less than the amount of latent heat required for the conversion of water into steam, it follows that after the temperature of the water fell below 212°, water and not steam must have been carried over with the air.

If figures are made upon the first two runs where the temperature was maintained above or near the boiling-point, the data are: Temperature at starting, 324°; on return, 198°; loss, 126°. Water evaporated, 42.3 lbs. Units at 126° = 5330.

Weight of water at starting, 310 pounds; on return, 267.7 pounds.

Thermal units at start,	$310 \times 324 =$	100,440
Thermal units on return,	$267.7 \times 198 =$	53,004
Loss of thermal units . .		47,436
Accounted for by sensible heat-units as above		5,330
Leaves unaccounted for . .		42,106

If 1000 units per pound be allowed latent for water, 42,300, the difference is therefore fully accounted for, and proves that where air is passed through hot water the water removed carries off not only the units of sensible heat due to the difference in temperature, but also cools the remaining water to the extent of 1000° for every pound of water removed.

Another important observation may here be made. In the 3 round trips of $9\frac{3}{4}$ miles the loss of heat-units in the tank was 55,800. If the heat had been maintained at 324° by means of a small naphtha or petroleum stove yielding more than 20,000 units in combustion, it is reasonable to assume that 15,000 units could be utilized, and consequently 4 pounds, costing not more than 3 cents, would supply the units for more efficient reheating at a cost of 3 mills per mile run of motor. This reheating, it will be remembered, doubles the run with a given volume of air; in other words, 5 miles would be added to the run of the motor at a cost of 3 cents, which is a maximum cost.

Small as this is, it is still higher than Mr. Hardie's estimate for hot water drawn from stationary tanks. He allows $\frac{1}{8}$ of the coal used in compression. In this case 6 pounds of coal should furnish the 55,800 units, at a cost

of one cent; but by referring to the record, it appears that where the temperature of the water was 324° at the start, the run was made with 70 pounds pressure, and could probably have been made at 65 pounds if the temperature during the run had been maintained at 324°. At this rate the air evaporated per mile would have been reduced from 300 cubic feet to 240.

Another observation on this very important subject of reheating should be made. The air was not only expanded by the heat, so as to exert a higher pressure from that cause, but there were carried over 62.1 pounds of water in the form of steam, which would be equivalent to 1700 cubic feet of air at atmospheric tension, with the additional advantage of a warm exhaust and no possibility of frost. This accession of motive power in addition to the elevation of temperature will account for the fact that double runs were secured by the simple expedient of passing the dry air through a small tank containing only 5 cubic feet of hot water.

VIII.

ECONOMICAL MODES OF COMPRESSION.

In reference to the most economical method of furnishing supplies of air to the motor tanks, Mr. E. Hill, of the Norwalk Iron Co., who has had very extended experience, gives the following information:—

There are four methods in all of charging air tanks.

First. A reservoir capacity two, three, or four times the size of the tanks and containing a pressure of air

much greater than the pressure in the tank, so that when the valve between tank and stationary reservoir is opened and the pressures equalized, the resulting pressure in the tank will be the pressure desired.

Next. Stationary reservoirs charged to a pressure somewhat higher than the pressure desired in the tank and said stationary reservoirs brought in connection successively with the tank to be charged.

Third. A reservoir of very great size in comparison with the size of tank to be charged, so that for practical purposes the air can be considered as being drawn from a reservoir of infinite size.

Fourth. Direct pumping into the tank itself.

Referring to plan No. 1, we have considered that a reservoir three times the capacity of the locomotive tank is employed. This reservoir must be charged to a pressure of 53.33 atmos. in order that the pressure in reservoir and tank shall be 42 atmos. after the reservoir and tank have equalized their pressures. The duty then for a compressor will be to pump up that tank from 42 atmos. to $53\frac{1}{3}$ atmos. at each charging of the locomotive. If this work is done in one minute, it will require 2380 H. P.

Referring to plan No. 2, it will be assumed that three stationary reservoirs are used, and that each reservoir is of a size equal to the size of the tank on the locomotive. If these three reservoirs are charged to 47 atmos., and reservoir No. 1 is brought into connection with the tank of the locomotive, the pressure will equalize between the two and become $27\frac{1}{2}$ atmos. If now No. 2 tank is brought in connection, the pressure will become 37.25. If the third reservoir is now connected, the pressure will

become 42.12 atmos. Therefore, the duty required of the compressor is to pump up tank No. 1 from 27½ atmos. to 47 atmos., tank No. 2 from 37.25 to 47 atmos., and tank No. 3 from 42.12 to 47 atmos. This will require 2119 H. P. if done in one minute.

Referring to the third plan, in which the reservoir is of very great size, so that practically when the locomotive is charged there is no fall of pressure, the duty then of the compressor is to compress all of its air to 42 atmos. To supply the locomotive under these circumstances, each minute will require 1828 H. P.

The fourth plan, for direct pumping, presumes that absolutely no reservoir at all is used. Here the duty is simply to raise the pressure in the locomotive by direct pumping from eight atmos. to forty-two atmospheres. This will require 1706 H. P. if the work is done in one minute.

It will, of course, be noticed from the above comparisons that the fourth plan as regards power is by all means the one to be preferred; but it is not presumed that such a large quantity of air can be compressed so quickly and cooled so rapidly in one minute. Therefore calculation should be made, if a locomotive is to be dispatched every minute, to have a number of locomotives at the charging station at the same time, so that each of those locomotives could be under treatment from ten to fifteen minutes, in order that the air may have *time* to cool during the process of compression, but the total power will be such as to dispatch one locomotive every minute.

Answering other questions regarding the power to do the above work in 2½, 5, and 10 minutes, it may be said

that follows in inverse proportion. The above calculations are taken at a mean between isothermal and adiabatic compression, and are as near as possible what will be actually found to be the result in practice.

As regards the expense of running compressors, it is proper to state that the above calculations give the power in H. P. The expense of a H. P. is a well-settled matter according to the style of engine which is employed to produce it.

Frost from Expansion of Air.

It is a common, but very erroneous, opinion that serious difficulty is experienced in compressed-air engines from the intense cold produced by expansion and the closing of the exhaust passages by frost. No difficulty of the kind has ever been experienced in the use of the Hardie motor, even with cold air; but the practice of reheating, which should never be omitted, since it doubles the power at nominal cost, raises the temperature of the exhaust air above the freezing-point. In the tests made on the Second Avenue Railroad in 1879, it was found that, although the air from the compressor was cooled by passing it through water, there was no deposit of frost. The writer explained the fact on the theory that the capacity of air for moisture was not increased by density, and that the escaping air was too dry to deposit moisture even at a very low temperature. Mr. Hill, of Norwalk, confirms this opinion, and has given the following very satisfactory explanation :—

"Your statement regarding the water left in compressed air agrees exactly with the authorities on this question

as we understand them. The density of the air does not have an appreciable effect on the amount of moisture within a given space. The temperature, however, affects it according to well-settled results. It has been observed that the higher that air pressures have been the less liability there is to freezing at the exhaust. This result is in opposition to the preconceived opinions regarding the use of compressed air. Air of 15 to 30 lbs. pressure when expanded in an engine almost uniformly gives trouble at the exhaust. Therefore it has been argued that air at very high pressure—several hundred pounds—would give a proportionate amount of trouble there, freezing because its exhaust could be expected to be so very much colder than the exhaust of air of lighter pressure; but, as I have stated above, it has been found that the air at high pressure does not give this anticipated trouble, and in fact does not give as much trouble as does air at lower pressure. The reason for this is readily explained. Air at the low pressure, when it is exhausted, will be cold enough to freeze whatever moisture there may be in it. Air at the high pressure will, of course, be cold enough on exhaust to freeze the moisture that may be in it. But to get the same power from low-pressure air as we can get from high-pressure air, we must use of the low-pressure air very many more cubic feet. As when temperatures are equal the moisture in the air depends upon the volume, it follows that for a given power when obtained from low-pressure air we have passed through our engine much more moisture, and, as it all freezes in any event, we run a greater risk of being stopped at the exhaust. Taking another case where air at 600 lbs. pressure is stored in the reservoir

of a pneumatic locomotive and is then, through a reducing valve, drawn down to 100 lbs. pressure for use in the cylinders, we would find that the air at 100 lbs. pressure would be only $\frac{1}{6}$ saturated with moisture. The air at 600 lbs. pressure would be fully saturated. The moisture in one cub. ft. of 600 lbs. air being by the process of reduction distributed through six cub. ft. of 100 lbs. pressure, the result is that the air of 100 lbs. pressure is, as stated above, only $\frac{1}{6}$ saturated. Or, stating the case in another way, a cubic foot of air at 100 lbs. pressure which has been obtained from a tank holding 600 lbs. of air would contain only $\frac{1}{6}$ the moisture which would be found in a cub. ft. of air at 100 lbs. pressure, which had been obtained by compressing atmospheric air to 100 lbs. pressure.

"The above statements would all hold true without regard to the method of cooling. The question only would be, what is the temperature of the air, and has it been quiescent long enough to allow the moisture to be dropped? The statement which I have heard made, that blowing air through water dried it by reason of the affinity of the water for the moisture in the air, is, in my opinion, a lame explanation. The process dries the air simply because it cools it, and any other method of cooling would accomplish exactly the same result."

Considerable space has here been given to the subject of compressed air as a propelling power on street railroads, for the reason that writers who treat upon the subject of street motors almost invariably pass it over with a few disparaging remarks as something that has been tried and found wanting. It is really amazing to find so vast an amount of ignorance accumulated on this subject. The

reasoning seems to be: Well, this thing has been tried; if it had any merit, why was it abandoned? And no trouble is taken to inquire into the merits of the motor, or the causes which prevented its general use,—causes having no connection whatever with the merit or the practicability of the invention. If the facts that have been stated will lead intelligent engineers and capitalists to investigate, there will soon be a change of public opinion upon this subject, and the best of all modes of propulsion for street service will not be cast aside for other systems far more expensive in plant and operation, and far less satisfactory in results, both to the public and to capitalists.

IX.

COST OF OPERATION OF THE COMPRESSED AIR MOTOR FOR ONE DAY—SIX MILES DOUBLE TRACK.

FOR the determination of this question the data can be relied upon with more confidence than in any of the other cases under consideration.

It has been demonstrated that the motor can be run with 300 cubic feet of free air per mile, and that the compressor plant to furnish this volume of air for each of 60 motors will require not more than 600 horse-power, or 10 horse-power at the central station for each motor. Each horse-power requires $2\frac{1}{2}$ lbs. per hour of \$3 coal, so that the coal per motor per hour will be 25

pounds, to which the equivalent of 3 pounds must be added for reheating, making 28 lbs. per hour for a run of 6 miles. The consumption per mile run will, therefore, be $4\frac{2}{3}$ pounds, and the cost 7 mills per mile run.

This is the whole cost of fuel, not including interest and repairs, which are less than in other systems.

Cost of Plant and of Operation for the Pneumatic Motor.

Land, 22,000 square feet of ground, at $1.50	$33,000
Building	80,000
Engine, boiler, setting, etc., for 600 H. P.	30,000
Reservoirs, pipes, etc.	5,000
Cost for six miles double track	$148,000

Street Construction—One Mile, Double Track.

Track	$20,000
Paving, 9282 square yards, at $3	27,846
Total street construction	47,846
Cost for six miles	$287,076

Equipment.

75 combination cars and motors, at $3500	$262,500

Summary.

Power-house and plant	$148,000
Street construction	287,076
Equipment	262,500
Engineering, legal and miscellaneous expenses	20,000
	$717,576

Cost of Operation of Six Miles Double Track for One Day with the Pneumatic Motor.

Coal, 5760 miles run at 4⅜ pounds per mile—	
13½ tons, at $3 per ton	$40.50
Water, oil, and grease	6.50
Depreciation of plant and rolling-stock	78.00
60 Conductors, at $2	120.00
60 Drivers, at $1.75	105.00
Engineers and firemen at station	25.00
Car-house and other service	28.00
Repair of motors and cars	200.00
Repair of engines and compressors	15.00
Repair of track and buildings	50.00
Track cleaning, train, and shop expenses	25.00
Accidents	20.00
Legal and other expenses	10.00
General and miscellaneous expenses	50.00
	$773.00

Cost per mile . . . . 13.42 cents.
Of this amount the fuel alone costs 7 mills.

Compressed Air for Elevated Railroads.

The practicability of using compressed air instead of steam on elevated railroads and its superior economy were fully demonstrated, in 1880, on the Second Avenue Railroad, in New York.

A motor was constructed at the Baldwin Locomotive Works, upon the plans and under the immediate supervision of Robert Hardie, and was tested upon the Second Avenue Railroad; certificates of these tests by prominent officers and machinists of the road are in possession of the writer.

The section of the road upon which the experiments

were conducted is 8½ miles long, and there are 22 stations in this distance. The road is undulating and circuitous; an elevation of 80 feet has to be overcome in a part of the distance, and 6 quarter-circle curves of 90 feet radius. Intervals between trains, 3 minutes.

A report by Charles W. Potter, in 1883, gives a very full account of the test of the Hardie motor on the elevated road and its economic results. An extract is here given :—

"The Hardie engine, weighing 18¾ tons, was found capable, with a single charge of air, of hauling the regulation five car trains, full of passengers (weighing approximately 60 tons, or about 78 tons including the engine), the entire distance of the road, making all regulation stops to deliver and receive passengers, accomplishing the trips in the schedule time, and with sufficient surplus of air remaining to enable it to retnrn light to the engine depot, a distance of 5½ miles, the greater part up hill. The quantity of air expended in making these trips with trains was equal to 12,600 cubic feet at atmospheric pressure, and in returning light, 4600 cubic feet; making a total expenditure of 17,200 cubic feet. It may be mentioned that this distance is the utmost which the present steam locomotives travel without a fresh supply of water.

"The efficiency, and still more the economy, of an air locomotive increases with the magnitude of the scale on which it is constructed: and therefore, as the engine whose performances are given was built for experiments on the elevated railroad, and was necessarily limited in weight, it is clear that were it possible to increase the weight to 30 or 35 tons, as would probably be the case

in an underground railway, the storage capacity for air would be increased and a proportionately longer distance would be possible with a single change.

"Moreover, the weight of the London underground trains, in proportion to the weight of the engines that draw them, is *less* than in the case of the elevated trains in New York, and, as the stations are farther apart, still better results may be expected. In fact, it is urged that in point of efficiency air engines of the Hardie type can be constructed to meet all the requirements of every portion of an underground as well as of an elevated railway even better than steam, for the pure air discharged at each revolution will also aid in ventilation.

"The next and most important consideration is the cost, first of equipping the road, and secondly of operating it, and as in this particular it would be well to have all estimates on actual experiment, it is desirable to again revert to the results attained upon the elevated railroads in order to make a comparison with the steam engines there in use.

"As the storage reservoirs used in air locomotives are cheaper to construct than the boilers of steam locomotives, and as the machinery in the one case entails practically no more complication than in the other, it is clear that in point of first cost the balance is in favor of the compressed air locomotive; but the margin of saving is rather more than counterbalanced by the compressing plant necessary for furnishing the air. The builders of compressing machinery in the United States estimate that to furnish 12,600 cubic feet of free air (the quantity expended by the Hardie engine in a single trip) compressed to 600 pounds per square inch, which was the

storage pressure adopted in the engine now under consideration, and to furnish this supply every three minutes, the amount of horse-power required is 1285, and they are willing to guarantee the correctness of this estimate, and contract for the supply of the necessary plant.

"As the locomotives used have to be supplied with air at each end of the road, this amount of power must be duplicated; hence a total is necessary of 2570 horse-power, or say roundly 2600, to operate the particular section of the road referred to. On the whole, therefore, the first cost of equipping the road might be somewhat greater for air than for steam locomotives; but this, as will be shown later, would be more than counterbalanced by the reduced cost of operating. As it requires at least 36 locomotives to carry on this traffic, at three minute intervals, including switching and relays, each locomotive would be represented by about 72 horse-power of stationary plant, and this is the maximum that would be needed, as it is only during a few hours morning and evening that the interval between trains is so short as three minutes, and as it is obviously expedient to divide up the power into, say, four complete sets at each terminus, it would only be necessary to operate the whole of it during those few hours, and thus ample opportunity would be afforded for inspection and repairs.

"Strange as it may seem at first sight, considering that the power is used second-hand, so to speak, yet a very large saving is effected in point of fuel, and it is this saving, with that of the fireman on the locomotive, that turns the balance of economy greatly in favor of compressed air. The cost of operating is computable as follows:—

"The average rate of consumption in these steam locomotives is one ton per 60 train-miles, or about 45 pounds per mile. This is necessarily high, owing to the frequent stoppages. As previously stated, 2600 horse-power will charge a locomotive with compressed air every 1½ minutes, or 40 locomotives per hour, and each locomotive will haul a train 8½ miles, being 340 train-miles per hour. The stationary compressing engines need not consume more than 2 lbs. of coal per horse-power per hour, or say 2½ lbs. to make allowances and be on the safe side. Hence the consumption of fuel for 2600 H. P. will be 6500 lbs. per hour, and 6500 lbs. over 340 miles equals less than 20 lbs. per train-mile, not half the consumption of the steam locomotives, and only one-fourth the cost, as cheaper fuel may be used. Again, as the air locomotives require only one man to drive them, a considerable saving in the cost of labor is effected, even allowing for the comparatively small attendance necessary to work the stationary plant."

In the figures given by Mr. Potter, he estimated a saving of 17 pounds of coal per train-mile and 340 train-miles per hour. If this average should be maintained for only 12 hours, allowing for longer intervals at midnight and in the middle of the day, the saving of fuel would be 5780 lbs., or 2.89 tons per hour, 34½ tons per day, and 22,592 tons per annum, costing in the tender of engine probably $5 per ton, or $112,960 per year, the interest at 5 per cent. on $2,259,200.

But this is not all. The 36 engines require firemen, and deducting 11 to offset labor at the compressor plant, there will remain 25 men at $1.75 per day. This small

item amounts to $16,000 a year, the interest on $320,000 at 5 per cent.

What would be the cost of the compressor plant to furnish 12,600 cubic feet of free air in 1½ minutes = 8400 cubic feet per minute? The compressors, boilers, and engines can all be covered by $115,000, so that the saving in firemen alone would represent nearly three times the cost of the compressor plant.

How can there be any question, therefore, as to the great superiority of compressed air over steam for the operation of city railroads, whether surface, elevated, or underground?

Why Compressed Air is Not in General Use.

If, as stated, it has been demonstrated by actual results, both on surface and elevated railroads, that compressed air furnishes a mode of propulsion far superior to steam or horse-power and at the same time far more economical, affording superior public accommodation and larger dividends to the companies, requiring no trolley wires overhead, or cables beneath the surface, with not a single objectionable feature of any description, but many in its favor, why is not the system universally used? The question is pertinent, and the answer can be briefly given.

In 1879 public opinion was not sufficiently educated to regard this improvement with favor. Absurd as the objection then made may now appear, presidents of horse railroad companies declared that any car moving along a street without horses in front would frighten other horses even if there was no noise, and that many acci-

dents would occur and suits for damages be instituted; that the system could not be used without stuffing the skins of dead horses and running them on a low truck in front. This was the reason given to the writer by the president of a city railroad in Philadelphia, who declined to consider the question of the advantages of a change of system, and attempts to induce others to examine into the merits of compressed air proved equally unsuccessful, so that efforts were discontinued.

When it is considered that both cable and electric roads run without horses and cause far more noise than the pneumatic engine, the objections made in 1879 appear very absurd.

But this was not the only cause of failure to secure the adoption of the improvement. Mr. Hardie unfortunately fell into the hands of irresponsible parties and parted with the control of his patents to a straw company, the collapse of which put an end to further efforts. Mr. Hardie afterwards accepted a position as superintendent of a locomotive works, and has recently filled the position of mechanical engineer of the Columbian Exposition at Chicago. The following is his own story of the causes of failure in the introduction of the pneumatic motors:—

"The proper way to have met all objections was not by discussion and argument, but by a practical demonstration. Railroad men were not satisfied with a few exhibition trips of the motors, although, as a general rule, the performance was considered very satisfactory so far as it went; but they all wanted to see a railroad operated exclusively and successfully; and until then no railroad would adopt the system. As it required

capital to do this, and as the motor company had practically none, the enterprise was never carried beyond the experimental stage. It is true that this company was capitalized at $1,000,000, but that needs explanations. Those who organized the company were men of no financial standing, and the stock was all issued to them, without payment or consideration, except the expenses of organization and a few preliminary tests. In order to evade the law which required that the stock should be paid for at its full par value, a valuation of $1,000,000 was put upon some patents which one of their number held in trust; and the stock was issued to him in consideration of said $1,000,000 worth of patents: said trustee then divided the stock, as previously understood and agreed on, including a small percentage to the patentees. In order to provide 'working capital,' the stockholders assessed themselves in a percentage of their stock, which was set aside as 'treasury stock,' to be disposed of at whatever price it could be sold for. In this way some money was raised, but not enough to do any real business, and consequently nothing was done beyond making exhibition runs of the motors, and getting flourishing accounts into the newspapers, on the strength of which the individual members 'peddled' their stocks.

"Among those who bought stock was a gentleman of means, as well as culture and refinement, and strict integrity. In some way he was induced to loan the company money from time to time on its notes, and this kept it alive a while longer. Indeed it began to look as if some real business might be done after all. A compressed-air locomotive was built and tested on the

elevated railroad, which succeeded in hauling their four-car trains, loaded with passengers, the whole length of the road; making all the stops to receive and deliver passengers, making the schedule time, and, in fact, doing practically everything which the steam locomotives were required to do. At the end of the trip it was found that a sufficient surplus of compressed air remained in the reservoirs to insure against possible failure; and, as will be shown later, the economy was beyond question. For some unexplained reason, however, this success was not followed up, and eventually a sudden and complete collapse was brought about by the sudden and sad death of the gentleman referred to, in whose estate the company's overdue notes were found.

"The inside workings and manipulations of this straw company, with paper capital, would make interesting reading; but I trust enough has been said in the brief space allowable here to show that it was not an organization well calculated to make a commercial success of such an undertaking, and is my explanation for the project being abandoned. Needless to say, it was a great disappointment to me. Those desiring to investigate further can be furnished with plenty of evidence as to the practical utility of the system, and the mechanical success of the experimental motors."

Notwithstanding the success of the air motor on the Second Avenue Elevated Railroad and the favorable indorsement of the officers who made the tests, the directors were not inclined to incur at that time the expense of a change of plant, and the death of the capitalist who had advanced the money for the construction of the motor caused the abandonment of further efforts. It was in

fact impossible for Mr. Hardie to take another step, as he had parted with his patents for a stock consideration which proved to be worthless, and the company had hypothecated these patents, which were its only assets, for loans that they were unable to pay.

Mr. Hardie has prepared new plans with valuable improvements, the old patents have nearly all expired, and the way is open for the introduction of air motors without fear of annoyance by hostile litigation.

X.

OTHER AIR MOTORS.

THE newspapers from time to time publish notices of new motors which have a very brief existence and never pass the experimental stage.

Some of these have been misnamed compressed air motors, but the air, instead of being applied to operate a piston in a metal cylinder, is used to communicate motion to some intermediate machinery, and the action depends upon the application of principles essentially different from those that have been utilized in the compressed air motors of Hardie and Mekarski.

In one of these proposed systems a line of pipes about 6 inches in diameter was laid under ground in the middle of the track and rotated by steam, compressed air, or other power. An arm like the arm of a cable-grip car passed through a slot, like the slot of a cable-line, and carried small wheels which could be changed

in position at the pleasure of the motor-man, and the rotation of which by contact with the revolving pipe communicated motion to the car. The speed was regulated by varying the angle at which the small revolving wheels were set. After an expenditure, it is said, of many thousands of dollars, this device proved a failure, and has been abandoned.

Nearly half a century ago the engineering profession was entertained with occasional notices of a so-called atmospheric railway, which consisted of a pipe 36 inches, more or less, in diameter, laid under ground. On the top was a continuous slot, 2 inches wide, covered by a flap-valve of leather, rubber, or other elastic material. Inside the pipe was a piston carrying an arm through the slot like the arm of the grip in a cable-car. By exhausting the air in front, the atmospheric pressure behind would communicate motion to the piston, and as it moved the arm would open the flap-valve, which would close again behind it as it passed. A trial of this plan was made about 1840, on the West London Railway, and also on one or two other railways, but all were soon abandoned as unsatisfactory.

The result of these trials clearly proved that the atmospheric railway system could not stand in competition with that of the locomotive engine, unless in some peculiar situations. *Chambers's Encyclopedia* refers to this contrivance, and states that the expense and care necessary to keep the tube with its valve in good working order led to the removal of the atmospheric mechanism from the various railways on which it was established, so that the history of atmospheric railways may be ranked under the chapter of failures. They

survive only in the form of pneumatic dispatch tubes for the conveyance of parcels, many of which are used in London.

After fifty years, and in the face of this experience, it is calculated to promote a smile to read a notice in the papers of "*A New Motor*," and of the existence of a pneumatic power and motor company, which has revived the old atmospheric railway scheme, with the difference that, instead of the continuous slot and elastic flap-valve, the slot is covered by a continuous row of rigid slide-valves, which are opened by a projection in the power-bar as the piston passes along the tube, and closed by a similar device after its passage. There is no reason to believe that this device can be more effective than the old flap-valve; but, on the contrary, must be more difficult and expensive to construct and maintain, and the loss by leakage in a continuous line of valves must be excessive.

XI.

CABLE AND ELECTRIC ROADS.

CABLE and electric roads are too well known to require any description. Many publications have been made, giving details of construction and explanation of principles, which would be entirely out of place in this volume, the object of which is chiefly to institute a comparison between the different systems now in use, or proposed to be introduced, as to cost of plant and of

operation, and the general results that would follow their adoption, as regards dividends upon capital and public accommodation.

In the attempt to institute such comparisons, great difficulties are experienced from the unreliable character of the data furnished in public reports. There has been no uniform system of keeping accounts. Items of expense are sometimes included in one report and omitted in another; in some, interest will be included and in others excluded. The cost of plant varies greatly in different localities, and includes items, some of which are independent of, and others, in part, at least, proportioned to the length of road operated.

Comparative estimates, to be of any value, or inspire any confidence in the results, must be based upon similar conditions as to the character of the work, the length of line operated, and the volume of traffic.

As the data furnished by census, State, and other reports apply to roads of diverse lengths, characters, and conditions, an attempt will be made to take differences into consideration and make comparisons as fairly as possible on a basis of uniformity. For this purpose a number of miscellaneous results and data will be given, and an estimate then attempted of the cost of plant and working of a road of given length and given volume of business operated by each of the systems proposed to be compared. When it is considered that the reported cost of plant per mile on one road may be three or four times as much as on another, and that reported earnings and expenses vary as one to two or more, the necessity of some uniform basis of comparison will be obvious.

It is proper, therefore, to assume uniform conditions, and a road will be taken six miles long in a paved city, laid in substantial manner, with double track, heavy rails, a volume of business sufficient to require one 16-foot standard car every two minutes for an average of 16 hours. Horse-cars making 4 miles per hour, and motors 6 miles, and a reserve of 20 per cent. of horses, cars, and motors for extra service and contingencies. This will require 72 cars for the motor lines and 108 for horse lines, and, for the sake of uniformity, the equipments will be supposed to be combinations of car and motor in one, and having the usual seating capacity for 20 passengers. Such cars can be used with all motors, except steam and gas, where separate motors will be required. The daily car mileage with the data given will be 5760 miles, and the annual mileage 2,102,400. The combination motor should have power sufficient to haul on ordinary roads one, and on level roads two, trailers to meet the requirements of maximum business.

To realize how little information can be derived from reports as to actual cost and expenses, where dissimilar conditions are not recognized, the following extract will be given :—

From *Chicago Street Railway Journal*, November, 1892, article by Mr. M. Ramsay, chairman of committee, after correspondence with every cable road in the United States, and with the representative electric and horse railroads :—

Operating Statistics of Eight Cable Roads.

	Maximum.	Minimum.	Average.
No. of grip cars daily . .	193	5	50
" trail " " . .	298	5	74
Daily mileage grip cars, each .	127	70	98
" " trail " " .	123	70	95
Receipts per car-mile, including mileage of trail cars .	29.84	15.10	20.20
Gross operating expenses per car mile, exclusive of fixed charges	41.00	6.75	16.70
Net earnings per car-mile .	8.4	4.9	6.97

For Seven Electric Roads.

	Maximum.	Minimum.	Average.
Motor cars daily . . .	280	5	57
Trail " "	5	4	4½
Daily mileage, motor . .	127	70	101
" " trail . . .	120	56	88
Receipt per car-mile, including mileage of trail cars . .	40.28	13.5	24.
Gross operating expenses per car-mile	25.44	9.0	12.5
Net earnings per car-mile .	14.34	0.0	6.04

Notes from Street Railway Journal of July, 1892.—
Ten Cable Roads.

	Maximum.	Minimum.	Average.
Length of line	11.69	2.70	7.32
Length of all tracks . . .	23.38	5.44	14.29
Number of grip cars . .	116	12	60
" trail " . . .	380	8	102
Indicated horse-power of engines	3400	200	1329
Cost per mile of line .	$683,840	$159,227	$290,940

Ten Electric Roads.

	Maximum.	Minimum.	Average.
Length of line	11.71	2.80	5.56
" all tracks . .	16.35	2.80	6.72
Number of motor cars . .	47	2	12
" tow cars . .	15	2	4
Indicated horse-power . .	1050	35	237
Cost per mile of line . .	$98,749	$8,807	$36,145

Ten Cable Roads—Twelve Months' Operation.

	Maximum.	Minimum.	Average.
Car mileage	6,290,172	310,331	2,327,625
Passengers carried . .	36,218,807	1,340,820	10,199,569
Passengers per mile operated	4,261,036	437,628	1,355,965
Operating expenses per car mile	21.91 cts.	9.39 cts.	14.12 cts.
" " per passenger	4.28 "	2.43 "	3.22 "

1242 standard car-miles per mile of line is an average of daily operation of cable lines.

A comparative estimate of cable and electric roads, of *equal capacity,* gives nearly equal cost per mile. The cables are generally metropolitan and the electric suburban.

Ten Electric Roads.

	Maximum.	Minimum.	Average.
Car mileage	702,770	19,754	244,210
Passengers carried	2,752,382	60,217	803,121
" " per mile .	470,090	14,795	222,645
Operating expenses per car mile	36.04 cts.	8.34 cts.	13.21 cts.
" " per passenger	11.82 "	2.71 "	3.82 "

Extracts from Census Bulletin of April 24, 1892.

The bulletin was prepared by Mr. C. H. Cooley, under the supervision of Mr. Henry C. Adams, of the Interstate Commerce Commission, and covers statistics of 50

lines of street railway, 10 operated by cable, 10 by electricity, and 30 by animal power. The total cost of the 10 cable roads, including equipment, is given as $26,-351,416. The total number of passengers carried was 101,995,695, at a total cost of $3,286,461. The operating expenses per car-mile were 14.13 cents, and the operating expenses per passenger carried 3.22 cents. The length of all tracks, including sidings, was nearly 143 miles.

The total cost of the 10 electric roads, including equipment, is given as $2,426,285. Total track mileage of 67.22 miles. Passengers carried, 8,031,214, at a cost of $326,961, or 13.21 cents per car-mile and 3.82 cents per passenger.

The expenses per car-mile on cable roads varies from 9.39 cents to 21.91 cents; on electric roads from 8.34 cents to 36.04 cents.

The density of passenger traffic is about six times as great upon the cable as upon the electric railways.

The editor of the *Street Railway Journal*, of Chicago, gives, from his own figures as secretary of the Chicago City Railway for 1890, cost of operation of cable cars, 9.65 cents per car-mile.

The *Philadelphia Record* gives, for three months on the West End Railway, of Boston :—

Expenses per Car-Mile.

April	.	Electric, 21.75 cts.	.	Horse, 24.54
May	.	" 22.36 "	.	" 24.04
June	.	" 20.37 "	.	" 23.52

The Earnings were—

April	.	Electric, 34.05 cts.	.	Horse, 31.77
May	.	" 33.43 "	.	" 34.22
June	.	" 42.71 "	.	" 36.85

Charles H. Davis, C. E., in a printed circular, gives some interesting facts and figures in regard to electric roads :—

Cost, including all Plant except Real Estate.

A road of	2	miles with	8	cars costs	. . .	$70,000
"	3	" "	10	"	. . .	92,000
"	4	" "	12	"	. . .	110,000
"	5	" "	15	"	. . .	128,000
"	6	" "	20	"	. . .	165,000
"	8	" "	25	"	. . .	199,000
"	10	" "	30	"	. . .	248,000
"	12	" "	40	"	. . .	318,000

Investment and Operating Expenses Compiled from Edison Co.

	Electric.	Horse.	Cable.
Real estate, road, and equipments per mile of street	$38,500	$33,406	$350,325
" " " " " " " track	27,780	31,093	184,275
Car-miles per annum per mile of street	76,158	43,345	309,395
Passengers carried per annum per mile of street .	237,038	251,816	1,355,965
" " per car-mile	3.10	5.80	4.38
Operating expenses per car-mile, cents	11.02	24.32	14.12
Interest at 6 per cent. on investment per car-mile, cts.	3.03	4.62	6.97
Total interest and expenses per car-mile, cents . .	14.05	28.94	20.91
Cost per passenger carried, interest excluded . . .	3.55	4.18	3.22
" " " " " included . . .	4.53	4.98	4.77

The cost of *power* on horse railroads has averaged as follows :—

New York City . . .	8 to 9	cents per car-mile.
Philadelphia . . .	9 to 10	" " "
Chicago	10 to 11	" " "

CONDITIONS, AS PER DAVIS CIRCULAR.

Day of 18 Hours.

Speed.—Electricity, 6⅝ miles per hour, 120 miles per day. Horses, 4 miles per hour, 72 miles per day.

Depreciation.—Electricity (of power), 15 per cent. Horses, 20 per cent. Car repairs: Electricity of motors, 20 per cent.; of cars, 10 per cent. Horse-cars, 5 per cent.

Repairs.—Track and line repairs: Electricity, 15 per cent. Horses, 10 per cent.

Service.—Three men per car: Electricity, $1.87 each. Horse, $1.60 each.

Cost of Track and Line per Mile.—Electricity, $10,000. Horse, $5000.

Value of Car.—Electricity, $3000, with motor. Horse, $1900, with 6 horses. Coal, 4 pounds per H. P., $4 per ton.

Average Operating Expenses of 22 Electric Roads per car-mile.

	Highest.	Lowest.	Average.
Maintenance of road-bed and track (cents)	1.80	0.10	.54
" line	.95	.01	.12
" power plant	.86	.05	.36
Cost of power	4.95	.48	1.96
Repairs on cars and motors	5.24	.59	1.80
Transportation expenses	9.47	2.74	4.98
General expenses	2.95	.79	1.26
Total	22.99	7.80	11.02

Another statement, including 7 electric roads, gives an average for—

Operating expenses, per car-mile	9.83 cents.
Cost per passenger carried	3.28 "

Estimates of Cost.

The comparative estimates of cost by the different systems will be made, as previously stated, by assuming similar conditions in all cases, viz.: Length of road, 6 miles; of single track, 12 miles. Cars in use on motor lines, 60; reserve, 20 per cent.; total, 75. Horse lines, 90, regular; 112, total. Speed, motor lines, 6 miles per hour; horse, 4 miles. Time, 16 hours per day. Daily motor mileage, 96 miles each; daily motor mileage total, 5760 miles. Daily car mileage of horse-cars, 64 miles each; daily car mileage total, 5760. Number of horses to a car, 8; total horses, with reserve, 900.

On many roads the speed is greater and the car mileage proportionately increased; but for a comparative estimate these figures will answer as well as others.

Conductors, engineers, motormen, and gripmen will be allowed $2 per day; fireman and drivers, $1.50.

For horse-stalls it will be proper to allow stalls 5 by 9 and 5 feet to middle of passage; total per horse, 70 square feet. For each car, 250 square feet, to allow for passages and for price of lots, $1.50 per square foot. To utilize space, cars can be placed on the ground floor, and horses partly on first and partly on second floor. The space required for cars on the horse line will be 28,000 square feet, and for horses, 63,000; in addition to this, about 2000 square feet must be allowed for offices, making a total of 93,000, or 100,000 square feet of floor space. Of this, 20,000 feet of first floor can be used for stalls, and all of the second floor, so that the whole ground area will be 50,000 square feet.

Horse Railroads.

Cost of Plant.

Track, 1 mile of double track, laid with 65-pound rail, including ties, spikes, etc.	$20,000
Paving, 9282 sq. yds. granite paving, 14 feet wide, 4 feet between track, and $1\frac{1}{2}$ feet on each side, at $3 per square yard . .	27,846
Cost of one mile	$47,846
Cost of six miles	$287,076

Car-sheds, Stables, and Offices.

Land, 50,000 square feet, at $1.50 . .	$75,000
Buildings, offices, car-sheds, and stables .	80,000
Total for land and buildings	$155,000

Cars and Horses.

900 horses, with harness, wagons, etc., $150 .	$135,000
112 cars, $1000	112,000
	$247,000
Total cost of plant for six miles . .	$689,076

Expenses of Operation.

Feed for 900 horses, at 34 cents per day . .	$306.00
Repairs of harness, $1\frac{2}{10}$ mills " " . .	10.80
Shoeing horses, $6\frac{3}{10}$ mills " " . .	56.70
Stable expenses, 1.15 cents " " . .	103.50
Replacing horses, $6\frac{3}{10}$ mills " " . .	56.70
	$533.70

Per horse per day, 60 cents ; per year, $219.

Per car-mile for stable expenses, $\frac{52370}{5760}$, 9.26 cents.

OTHER EXPENSES.

The other expenses of operation can be taken from the former estimate based on the Second Avenue Railroad data by—

Cars, repairs, conductors, and drivers, per car-mile	8.00 cents.
Track repairs	1 68 "
General and incidental expenses	5.30 "
	14.98
Add expenses of power, as above . . .	9.26 "
Total expense of horse-car service per car-mile	24.24 cents.

CABLE ROADS.

Notes from Fairchild on Street Railways.

The average horse-power to 1000 feet of cable is 4.6.

The power to move cable alone is from 35 to 75 per cent. of indicated horse-power of engines at station.

To determine approximately the amount of steam horse-power required for a line less than 10 miles of rope, allow 4-horse power to each 1000 feet of rope, each 90° bend equal to 1500 feet straight, with addition of 3-horse power for each car and 60 horse-power for machinery.

If the power required for propulsion of cars be taken at 3 H. P. per car, on line including reserve, the power required for 75 cars would be 225 on the line; and as this is generally estimated at 40 per cent. of the steam horse-power at the central station, 60 per cent. being absorbed by friction and other resistances of rope and machinery, the power to be provided in engines and

boilers would be 562 H. P., or, in round figures, 600 H. P.

If the second rule be applied, 12 miles of cable = 63360 feet, and at 4 H. P. per 1000 feet = 252 H. P. Allow 4 right-angled turns in the 6 miles; thus 4 × 1500 = 6000, and 6 × 4 = 24 H. P. to be added for turns.

75 cars at 3 H. P. per car = 225 H. P., and the allowance of 60 H. P. for machinery makes the total 561 H. P., or almost the same as before.

For electrical lines the actual percentage of the steam-power utilized at the motor car is said to be from 30 to 40 per cent., so that the loss in transmission may be assumed as the same as in cable lines, 60 per cent., and the power required for propulsion is also nearly the same. This will make the steam-power required for cable and electric lines at the central station about the same.

For a pneumatic or compressed air line, running 75 cars at intervals of 2 minutes, the quantity of free air required per minute is 1800 cubic feet, and the horse-power required about 550, so that in all these systems the power required at the central station is practically the same for equal work on the track; but while 60 per cent. of the power on cable and electric lines is lost in transmission, on the compressed air line the power lost in compressing the air is fully restored in reheating, as has been shown, and there is no loss in transmission; but it requires much more power to operate a motor than to move a given weight by direct application of the power of a rope through a grip. This equalizes the power required at the central station.

In computing the cost of plant and of operation of cable roads, the large area occupied by stables will be dispensed with, but the car-sheds must be retained and

a separate building is required for power-house. The number of cars being 75, will require 18,000 square feet and the offices 2000 square feet. The power-house and plant will require about 100 × 200 = 20,000 square feet; in all, 40,000 square feet.

The track, so far as rails and paving are concerned, will be the same as estimated for horse roads; but the special constructions required for the use of the cable add very largely to the expense.

Power-house, Car-house, and Machinery.

Real estate, 40,000 sq. ft. ground, $1.50 . .	$60,000
Buildings	80,000
Engines and boilers, settings, etc., 600 H. P.	30,000
Driving machinery	40,000
Foundation, heaters, pumps, and sundries .	10,000
Cost for 6 miles	$220,000
Average cost for one mile	36,666

Estimate for Street Construction on One Mile of Double Track.

Track per mile ([illegible])	$20,000
9282 square yards paving, $3	27,846
6600 cubic yards track excavation, 75 cts. .	4,950
2640 cast-iron yokes, 350 lbs. = 2,755,000 lbs., 1½ cts.	13,860
293 carrying sheaves, $3.75	1,100
7040 yards, 50 lbs. per yard, steel slot-rails, 2½ cts. per lb.	8,800
51333 lbs. manhole covers and frames, 1¾ .	898
3323 cubic yards Portland cement concrete, $8.50	28,333
5280 feet double-track laying, $1	5,280
Sewer connections	3,000
10727 lineal feet steel-wire cable, at 33 cts. .	3,576
Cost of one mile double track . . .	$117,643
Cost of six miles double track . . .	705,858

Special Construction.

Main vault at engine-house and fixtures	$8,000
Two end vaults with fixtures	5,000
Special sheaves, crossing curves, etc., curve	18,000
Total for 6 miles	$31,000

Rolling-stock.

75 Combination grip and passenger cars at $2200 each	$165,000

Summary of Cost of 6 Miles of Cable Line, Double Track.

Power-house, real estate, and buildings	$220,000
General street construction	705,000
Special street construction	31,000
Rolling-stock	165,000
Engineering, legal, and miscellaneous	20,000
	$1,141,000
Cost of plant, one mile	190,166

In the attempt to estimate the cost of operation of a cable road based on the cost of one of shorter length, it does not seem reasonable to assume that the depreciation of cable will be simply in proportion to length, but in a much higher ratio. If length is doubled, the strain for any given length will also be doubled, and the friction and wear should be at least quadrupled. The wear of sheaves and pullies will also be increased to a great extent.

It would seem reasonable, in the absence of positive data, to estimate the expenses of repairs and removals of rope, sheaves, pulleys, and other street construction, including grips, as fully equal to the cost of repairs of motors in other systems; and if this be conceded, there will be a close approximation to identity of cost of power under similar conditions of the systems in general use.

Cost of Operation of 6 Miles of Double-track Cable Road per Day of 16 Hours.

13½	Tons of coal for 600 H. P., $3	$40.50
	Water and grease	6.50
	Depreciation of rope	140.00
	Depreciation of plant and rolling-stock	78.00
120	Gripmen and conductors, $2	240.00
	Engineers and firemen	25.00
	Car-house service, cleaning, inspecting, etc.	20.00
	Power-house expenses	40.00
	Track services	16.00
	Repairs of engines and machinery	26.00
	Repairs of cars, trucks, and grips	100.00
	Repairs of track and buildings	60.00
	Train, shop, and miscellaneous expenses	25.00
	Accidents	20.00
	Legal, secret service, and insurance	10.50
	General and miscellaneous	50.00
	5760 car-miles, cost	$897.50
	Cost per car-mile, $13.94 cents.	

This estimate, based upon prices given by various authorities, may be, in some items, in excess; but as the same prices will be retained for other systems, the effect will be to increase slightly the daily total without materially affecting the comparative estimates, which in this investigation are of most importance.

XII.

ELECTRIC LINES. (From Various Authorities.)

The cost of steam power-house plant complete, including building and smoke-stack, is rated, for high-speed and non-condensing engines, at from $45 to $60

per horse-power; for compound engines, from $60 to $75; and for electrical equipments, $35 to $45 per horse-power.

The usual unit of horse-power is 8 square feet of heating surface, evaporating 30 lbs. water per hour for sectional or water-tube boilers, and 15 square feet for tubular.

The following table gives, approximately, the horse-power at axles required to propel a 16-foot car, weighing, with its equipments and a moderate load of passengers, 5 tons, up grades of from 1 to 10 per cent., at the uniform rate of 8 miles per hour. On ordinary street-car tracks the traction is said to average about 20 lbs. per ton, but is sometimes more, and the commercial efficiency of the motors must be taken at 60 per cent. Thus, for a level track, the power required will be $5280 \times 8 \div 60 \times 20 \times 5 \div 33{,}000 \times \frac{100}{60} = 3.5$ horse-power at axles; and for grades, as follows, from 1 to 10 per cent.:—

0 = 3.5 H. P.	6 = 22.5 H. P.
1 = 6.5 "	7 = 25.5 "
2 = 9.5 "	8 = 28.5 "
3 = 13.0 "	9 = 32.0 "
4 = 16.0 "	10 = 35.0 "
5 = 19.0 "	

It is very important, in the management of an electrical plant, that the number of power units should be such that the disabling of one of them will not interfere with the success of the system, and the same remark is also applicable to other systems.

On the East Cleveland Electrical Road, 70 motor cars and 70 trailers are in daily use. One electrical horse-power is obtained for every five pounds of slack or four

pounds of nut coal. Evaporation, 7½ pounds of water per pound of slack.

Electric Traction Efficiency.

Of the total indicated horse-power developed by ordinary engines, 10 per cent. is consumed by the friction of the running parts.

The loss at the dynamo is from 10 to 15 per cent., being about 75 per cent. of the indicated horse-power as the station efficiency.

The line efficiency is generally about 90 per cent.

In the average of roads now in operation, the proportion of the indicated horse-power of the engines transmitted to the motor for propulsion of cars is between 55 and 60 per cent.

The average efficiency of the car motors themselves may be taken at 75 per cent., so that the propulsion of the horse-power of engines actually applied to propulsion of cars is 60 × 75 per cent. = 45 per cent. In a majority of cases it is stated that the actual commercial efficiency does not rise above 40 per cent. (Crosby & Hall, p. 228), which is about the same as in cable lines.

Cost of Items entering into the Construction of Electrical Railroads and Equipments, from Various Sources of Information.

Single-track railroad, average per mile . .	$10,000
No. 0 copper wire to make track a good conductor, per mile	400
Labor in laying wire and binding to rail, per mile	200
Wooden poles, 90 to the mile, placed, per mile .	600
Iron poles, 90 to the mile, placed, per mile .	2,500
Trolley wire, span wires, and insulators, per mile	700
Feed wire in place, per mile	1,000

1 mile single track, with wooden poles . .	$13,000
1 " " " wire poles . . .	15,000
Car bodies, ready for motors, 750 to 1500 dollars, average each	1,000
Long bodies, $1250 to $2000, each average .	1,625
Trucks for long cars	600
Two 15-horse motors, from 1800 to 2500 dollars.	
If one motor is used, from 1100 to 1800 dollars.	
Car ready to operate (electrical equipment, $2250)	3,500
For station power-plant complete, allow per horse-power	50
For station electrical plant	40
For both plants	90
Investment in station machinery, per car operated	1,350

Real estate may be generally covered by $50 per H. P. of station, or by $750 per car operated, but is extremely variable.

Average of 22 electric lines gives cost of power, as reported, 2.32 cents per car-mile; but published reports are usually unreliable.

	Cents.
Maintenance of line is covered by 5 per cent. of cost, say per car-mile	0.4
Maintenance of track is covered by, per car-mile	1.08
Maintenance of car bodies and trucks, per car-mile	0.72
Conductors and motor men	4.50

Summary of Expenses as given by Crosby & Hall, page 320 *of Electric Railway.*

	Cents.
Power delivered on line per car-mile . . .	1.35
Repairs on electric machinery of car . . .	1.00
Repairs on line	0.43
Conductors and motor men	4.50
Repair on cars and track	0.72
Maintenance of roadway	1.08
General expense	2.00
Accidents	0.25
	11.33

The cost of a trail car would be covered by 5 to 6 cents per mile. The expenses of the West End Railway of Boston for an average of 5 months were per car-mile operated by electricity:—

	Cents.
Motor power	7.44
Car repairs	1.33
Damages	0.43
Conductors and drivers	7.14
Other expenses	4.78
Total expenses	21.12

From which it appears that the actual cost on the West End Railway was nearly twice as great as the supposed average estimate above given by Crosby & Hall.

An estimate will now be made of the cost per car-mile of electrical railway service based on the conditions stated, viz:—

Line 6 miles double track, service two-minute intervals, cars 60, reserve 15, horse-power at station 600, daily mileage 5760 miles.

Power-house, Car-house, and Machinery.

Real estate, 40,000 sq. ft. ground at $1.50	$60,000
Buildings	80,000
Engines, boilers, settings, etc., for 600 H. P.	30,000
Station machinery	25,000
Foundations, heaters, pumps, and sundries	10,000
Cost for 6 miles	$205,000
Proportion for one mile	34,166

Estimate of Street Construction for One Mile of Double Track.

Track, one mile	$20,000
9282 square yds. paving, $3	27,846
Track wire laid	1,200
180 iron poles	5,000
Trolley wires, span wires, and insulators	1,400
Feed wires in place	2,000
Total street construction	$57,446
Cost for 6 miles	$344,676

Equipment.

75 car bodies, trucks, and motors, $3500	$262,500

Summary for 6 Miles.

Power-house and plant	$205,000
Street construction	344,676
Equipment	262,500
Auxiliary appliances	15,000
Special construction	5,000
Engineering, legal, and miscellaneous	20,000
Total cost for 6 miles	$852,176

Cost of Operation of Six Miles Double-track Electric Line per Day of 16 Hours.

13½ tons of coal for 600 H. P., $3	$40.50
Water, oil, and grease	6.50
Depreciation of plant and rolling-stock	78.00
120 motor men and conductors, $2	240.00
Engineers, firemen, and dynamo tenders	35.00
Car-house service, cleaning, inspecting, etc.	30.00
Power and car-house expenses	12.00
Track service	16.00
Repairs, engines, working of line, miscellaneous	26.00
Repairs of cars, trucks, and motors	140.00

Repairs of track, overhead construction, buildings	$80.00
Track cleaning, train, and shop expenses	25.00
Accidents	20.00
Legal, secret service, insurance	10.00
General and miscellaneous	50.00
5760 miles	$809.00
Cost per car mile, 14.04 cents.	

It appears that with equal length of road and equal car mileage the cost of operation of cable and electric lines is nearly the same on both. The depreciation of cable is about offset by the repairs of overhead wires, and dynamo tenders, other items the same.

General Summary.

Cost of Plant and of Operation for Six Miles of Double Track Operated by Horse-power—2-minute Intervals.

Land	$75,000
Buildings	80,000
Track and paving	287,076
Horses	135,000
Cars	112,000
Cost of plant	$689,076
Interest at 6 per cent.	41,345
Car-miles per annum	2,102,400
Interest per car-mile	2 cents.
Cost of operation, without interest	24 cents.
Cost of operation, with interest on plant	26 cents.
Cost of horse-power, not including drivers	9 cents.

Cost of Plant and of Operation of Six Miles of Double Track Operated by Steam Motors—2-minute Intervals.

Land	$60,000
Buildings and machinery of shops	100,000
Track and paving	287,076
Rolling-stock	300,000
Miscellaneous	20,000
Cost of plant	$767,076
Interest at 6 per cent.	46,025
Car-miles per annum	2,102,400
Interest per car-mile	2.09 cents.
Cost of operation, without interest, per car-mile	21.22 cents.
Cost of operation, with interest, on plant per car-mile	23.31 cents.
Cost of steam-power alone, without engineer or fireman per car-mile	9.50 cents.
Cost of fuel alone	2.65 cents.

Cost of Plant and of Operation of 6 Miles of Double Track Operated by the Ammonia Motor—Intervals between Cars, two Minutes.

Although the data furnished by the actual operations at New Orleans do not exhibit any economy as compared with steam, yet when it is considered that the principal work in generating power is done in a stationary instead of a locomotive boiler, in which fuel can be used at half price, with at least 50 per cent. more evaporation, it is reasonable to assume that in a properly constructed and operated plant there should be a saving, as compared with steam motors, of at least $75 per day in fuel. If separate motors are used, there will be no reduction in the cost of plant; but if the motors and cars are combined, less ground will be required, making a saving of $18,000.

Assuming minimum expenditures, the estimate will be :—

Land, 22,000 sq. ft., $1.50	$33,000
Building and apparatus	80,000
Track and paving	287,076
Rolling-stock, 75 cars and motors, $3500	262,500
Miscellaneous	20,000
Cost of plant	$682,576
Interest at 6 per cent.	40,954
Car-miles per annum	2,102,400
Interest per car-mile	1.95 cents.
Cost of operation per car-mile, without interest	19.92 cents.
Cost of operation, with interest on plant	21.87 cents.
Cost of power alone, without engineer or fireman	8.20 cents.
Cost of fuel alone	1.30 cents.

Hot-water Motor.

No separate estimate is required. The cost in every particular may be taken as the same as steam, both as regards plant and operation. Any slight saving by the first charge of hot water is fully offset by disadvantages and expenses in pumping back the water for reheating on return-trip. If not pumped back, the loss will be still greater.

Cost of Plant and Operation of 6 Miles of Double Track Operated by Gas Motors—2-minute Intervals.

As it is proposed in cities to use independent motors, the cost of plant will be taken as the same as steam, with a deduction of $500 each in the cost of motors, making them $2500. The fuel for motor and car will be taken at 1⅓ cents per mile run for the train. No fireman required.

Estimate.

Land	$60,000
Building and shop machinery . . .	100,000
Track and paving	287,076
Rolling stock	262,500
Miscellaneous	20,000
Cost of plant	$729,576
Interest at 6 per cent.	43,774
Car miles per annum	2,102,400
Interest per car mile	2.08 cents.
Cost of operation per car-mile, without interest	17.62 cents.
Cost of operation per car-mile, with interest .	19.70 cents.
Cost of power alone, without motor man, per car-mile	7.30 cents.
Cost of fuel alone per car-mile . . .	1.30 cents.

Cost of Plant and of Operation of 6 Miles of Double Track Operated by Compressed Air Motors—2-minute Intervals.

Land	$33,000
Buildings and machinery, for repairs . .	80,000
Engines, boilers, setting	30,000
Pipes and reservoir	5,000
Track and paving	287,076
Rolling-stock	262,500
Miscellaneous	20,000
Cost of plant	$717,576
Interest at 6 per cent.	43,055
Car mileage per annum	2,102,400
Interest per car-mile	2.05 cents.
Cost of operation per car-mile, without interest on plant	13.16 cents.
Cost of operation per car-mile, inclusive of interest on plant	15.21 cents.
Cost of power alone per car-mile, including repairs	4.10 cents.
Cost of fuel alone per car-mile . . .	7 mills.

Cost of Plant and of Operation of 6 Miles of Double Track Operated by Cable—2-minute Intervals.

Land	$60,000
Buildings	80,000
Engines, boilers, setting, and machinery	80,000
Track and paving	287,076
Rolling-stock	165,000
Street construction	448,924
Miscellaneous	20,000
Cost of plant	$1,141,000
Interest at 6 per cent.	68,460
Car-miles per annum	2,102,400
Interest per car-mile	3.25 cents.
Cost of operation per car-mile, without interest	13.94 cents.
Cost of operation per car-mile, with interest	17.19 cents.
Cost of power alone per car-mile	5.85 cents.
Cost of fuel alone per car-mile	7 mills.

Cost of Plant and of Operation of 6 Miles of Double Track Operated by Electric Lines—2-minute Intervals.

Land	$60,000
Buildings	80,000
Engines, boilers, setting, and machinery	65,000
Track and paving	287,076
Trolley wires, connections, etc., in street	56,600
Rolling-stock	262,500
Miscellaneous	20,000
Cost of plant	$831,176
Interest at 6 per cent.	49,870
Car-miles per annum	2,102,400
Interest per car-mile	2.37 cents.
Cost of operation per car-mile, without interest	14.04 cents.
Cost of operation per car-mile, with interest	16.41 cents.
Cost of power alone per car-mile	4.25 cents.
Cost of fuel alone per car-mile	7 mills.

XIII.

LOW-PRESSURE AIR MOTORS.

A METHOD of propelling street cars by the use of compressed air, at a low pressure of 100 lbs. per square inch, was proposed in San Francisco. The car reservoirs were to be of about 50 cubic feet capacity and placed overhead or under the seats, where they would be out of the way and would not interfere with the seating capacity. An underground pipe was to be carried between the tracks, the diameter of pipe 4 to 6 inches, and at intervals of 500 feet a nozzle was to be provided, to which attachment could be made to renew the supply of air in the reservoirs when necessary.

This system seems to have been proposed to remedy a purely imaginary difficulty. It was assumed that there was great loss of power and great expense in compressing air to high tension and that great economy would result from the use of lower pressure. It has been shown that the cost of fuel in compressing air to 500 pounds is only 7 mills per car-mile, which constitutes but about 5 per cent. of the whole expense of operation; and even if some economy should result from lower compression, which is doubtful, it would not compensate for the very serious objection of frequent stoppage to replenish the supply.

In the pamphlet which advocates the merits of the low-pressure system, objections to the high-pressure are stated; but there are none that have not been fully con-

sidered and answered. There is, however, an objection to the cable urged by the writer that has much force, and that is, that the power of the cable must be sufficient for the maximum business at the most busy hours of the day, and that this same power must be expended when the travel is a minimum, if there is only a single car upon the line. To avoid this great waste of power it is stated that some cable lines have stopped the machinery at night and substituted horse-power. Cables are economical only with a very large volume of business, and similar objections, although not to so great an extent, apply to electric lines. A current must traverse the whole line or section of line wire for a single car. There is always a serious loss in the transmission of power to long distances from the generating plant, and for this reason, as for others named, independent motors which carry their own power are far preferable.

Carbonic Acid Motor.

The *New York World*, of July, 1892, contained a long article presenting the claims of a new motor to be operated by carbon dioxide, usually called carbonic acid. It was claimed that 10 horse-power could be obtained from $6\frac{7}{10}$ pounds of the gas, at a cost of 20 cents for 24 hours; that pressures of from 1000 to 5000 pounds per square inch could be produced, and that this "wonderful motive fluid" was to be used even for road vehicles and for agricultural purposes.

The absurdity of such claims is self-evident. Carbonic acid condenses into a liquid at 570 pounds per square inch, and there can be no further condensation.

It is impossible to secure more power from the expansion of a gas than was expended in its compression; and even if a pressure of 5000 pounds were attainable, it could not be utilized, as was shown in the Beaumont tests, until reduced to a working pressure of about 200 pounds. Further comment is unnecessary.

XIV.

STORAGE BATTERIES.

No estimates have been made upon a line operated by the use of storage batteries, for the reason that no data are at present available. Up to the present time it is understood that the cost exceeds that of the cable and trolley lines; but it is claimed that greater economy has already been secured than by the use of horse-power, and that improvements are constantly reducing the expense. It may be that there is a future to the storage battery that will in time enable it to supplant the trolley, which would be a most devoutly to-be-wished-for consummation. The trolley is not only unsightly by its poles and overhead wires, and annoying by its loud humming noise, but it has proved destructive to life by contact with live wires; and the obstruction to the free use of the fire apparatus by overhead wires has caused losses greater than the cost of the lines themselves, of which a recent fire in Boston is an illustration, if the newspaper accounts can be relied upon. In addition to this, lines are liable to be deranged by electrical storms in summer and in winter by snow and ice on rails and

feed wires, which break the electrical connections. The latter evil might not be entirely remedied by the storage battery, but it would give an independent motor and avoid blockades all along the line from any trouble at the power-house.

The position will probably not be controverted that the motor and system of transportation that commends itself most highly to the approval of the public and of capitalists is the one which best fulfils the following conditions:—

1. Minimum cost of plant.
2. Minimum cost of operation, including interest on plant.
3. Independent motors not liable to stoppage in transit by derangement of station machinery.
4. Minimum disturbance of streets, pipes, and sewers.
5. Avoidance of unsightly structures, danger from shocks, or impediments to the free use of fire apparatus.
6. Surplus power in motor for attachment of trail cars at hours when increased capacity is demanded.
7. Freedom from liability to delay in transit from storms, ice, or sleet.

The several systems will be compared with reference to the above conditions.

Comparing the different systems that have been under consideration, by including in the operating expenses per car-mile the interest on the cost of plant, which is obviously the only true basis of comparison, the following results are presented in the order of relative economy. The first column gives the cost of operation per car-mile, including interest on plant; the second the cost of power

per car-mile, and the third the cost of fuel alone per car-mile in cents :—

Comparison of Motors.

	Cents.	Cents.	Cents.
Compressed air motors	15.21	4.10	0.7
Electric trolley lines	16.41	4.25	0.7
Cable lines	17.19	5.85	0.7
Gas motors	19.70	7.30	1.30
Ammonia motors	21.87	8.20	1.30
Steam motors	23.31	9.50	2.65
Hot-water motors	23.31	9.50	2.65
Horse-power	26.00	9.00	0.00

The relative economy in regard to cost of plant is as follows :—

1. Ammonia motor	$682,576
2. Horse-power	689,076
3. Compressed air	717,576
4. Gas motor	729,576
5. Steam and hot-water motors	767,076
6. Electric lines	831,176
7. Cable lines	1,141,000

Ammonia being the lowest in cost of plant, the other systems increase in the following percentages: Horse-power, 1 per cent.; compressed air, 5 per cent.; gas, 7 per cent.; steam or hot water, $12\frac{3}{10}$ per cent.; electric, 18 per cent.; cable, 40 per cent.

Ammonia Motor.—This system is independent, requires no overhead obstructions or disturbance of streets, carries its own power, and is not liable to interruption from trouble at the central station. It ranks fifth in economy of operation. There seem to be difficulties connected with its use, as it was abandoned after a short period of

use in New Orleans in favor of the hot-water motor as being "*cheaper and less troublesome.*"

Horse-power.—Horse-power needs no explanation. It is independent and generally reliable, but too slow for any approach to rapid transit. It requires no special construction in and causes no obstruction to streets, but in economy of operation it is at the foot of the list. It also creates nuisances by requiring stables and causing deposits in streets which, when dry, are blown into houses.

Compressed Air.—Compressed air seems to fulfil every condition as a perfect motive power. It stands at the head of the list in economy. In cost of plant it is only 5 per cent. above the minimum, but in cost of operation it is 8 per cent. below the next on the list. These motors are independent, there can be no losses by radiation or condensation. The charge of motors can remain for hours until used. The plant should always consist of a number of units, and the derangement of one will not affect the rest or disturb the operation of the line. If considered desirable, air can be transmitted, without sensible loss, to distant points to reinforce motors, if, from any cause, such supplies should become necessary. The speed is unlimited, except by municipal regulations. The track is a surface line requiring no disturbance of streets except to lay the track. There is no possibility of explosions, as with steam; no shocks, as with electricity; no stoppage by break of circuit from ice on rail or wires; no collisions from inability to detach grip, as in cable lines; and no occupation of valuable space by motor machinery, as all such machinery is under the floor of the car or beneath the seats, and entirely out of view; no skilled engineer

is required, as an ordinary car driver can learn to manipulate the lever in a single trip.

The motor can have any amount of surplus power to allow one or more trail cars to be attached under one conductor, when business is at a maximum, and thus secure public accommodation at a minimum of expense; and the ability to use increased power when needed does not cause a waste at other times, as no more air can be used at any time than is required for propulsion, and in running down grade the motor cylinders act as brakes and also as pumps to pump back air into the reservoirs.

It will thus be seen that there is not one of the conditions enumerated as desirable in a perfect motor that this does not fulfil; and, on the other hand, it is not known that a valid objection has ever been found, or, in fact, any objection, that has not originated in the ignorance of the maker.

The system is not only adapted to surface roads, but is also the best possible for elevated and underground roads. An explanation has been given of the causes which prevented its introduction after the satisfactory test of 1879 and 1880.

Gas Motors.—The Connelly Gas Motor, which is the only gas motor known to the writer, has been in process of development for six years, and seems to be a triumph of mechanical skill, combining strength with simplicity and compactness. It promises to be successful, but has not as yet the test of actual experience to inspire confidence.

This is an independent motor, free from all the defects of the horse, cable, and electric systems, and very economical in cost of fuel, although in several of the sys-

tems fuel forms a very inconsiderable portion of the total expense.

Steam and Hot Water.—These motors are classed together as equivalents. They are independent motors not liable to stoppage from derangement of any central plant; require no special construction or changes in surface roads. The disadvantages are that they must carry a supply of fuel, require a fireman and engineer, must use separate motors, are liable to accidents from explosions, and are objectionable from exhaust steam with its noise, and from smoke, cinders, ashes, and coals. In economy it stands fifth on the list, horse-power alone being more expensive. It is true that these motors may be run without firemen; but if the engineer is required to attend to firing, accidents and collisions may occur while his attention is diverted from the lookout, especially in crowded thoroughfares.

Electric Lines require ground connection below the rails and posts and trolley wires overhead. The motors are not independent, but must receive power from the central station, and are liable to be burned out by electric storms in summer or impeded by break of circuit from ice on track or feed wires in winter. Perhaps the most serious objection arises from the impediment to the free use of apparatus for extinguishment in case of fires, and the obstructive and unsightly appearance of poles and trolley wires. Electric lines stand second to compressed air in cost of operation, and sixth in cost of plant.

Cable Lines have the same disadvantage as the electric in being entirely dependent upon the central plant for the power of propulsion. Any stoppage there, or

break of cable, stops every car on the line, and repairs are difficult and cause very serious delays. A broken strand has sometimes prevented the detachment of the grip and caused most serious accidents, one of which occurred recently in Chicago. The plant is much more expensive than in any other system, but in economy of operation its place is third. Many of the reports show greater economy of operation for cable than for trolley lines; but cable lines are generally metropolitan, and have a much larger patronage than the electric; under similar conditions the superior economy disappears. For a light traffic the cable is not adapted.

In this review of the various street railway systems it has been the aim of the writer to state facts, so far as he has been able to procure them from the sources of information within his reach, and to make comparisons without bias. If he has appeared to lean favorably towards compressed air, it has been from a conviction of its superior merit, and from the fact that he was called upon professionally to devote much time and attention to the investigation of this subject, and therefore claims the right to give opinions with confidence. He is aware that there is a very general impression that compressed air has been tried and has been found wanting. This is a grave error; it has been tried and proved a great success. That it has not been generally used is the result of causes that have been here explained having no relation to its results. It is now in successful use in France, and has been for many years, although in mechanical construction the Mekarski motor is inferior to those constructed in New York and tested on the Second Avenue horse and elevated roads in 1879 and

1880, and the plans upon which these motors were constructed have been much improved upon by the inventor since that date.

XV.

COST OF CARBONIC ACID AS A MOTIVE POWER.

THAT carbonic acid is entirely too expensive to be used as a motive power can be readily demonstrated.

It was stated in the article from the *New York World*, referred to on page 139, that the cost of the gas is never more than three cents per pound, and the following figures are given, viz.:—

98 lbs. sulphuric acid, at $8 per ton . . .	.15 cents.
100 lbs. limestone, at $3 per ton	.784
Labor and compressing	.30
	$1.24

Producing 44 pounds of gas, at a total cost of $1.24, which is 2.8 cents per pound.

These figures are not far from the truth, but the power of the carbonic acid when produced is greatly overestimated.

Using the exact chemical equivalents, 99.75 pounds of pure carbonate of lime unite with 97.82 pounds of pure sulphuric acid and liberate 43.89 pounds of carbonic acid.

Sulphuric acid is generally sold at one cent per pound, but in large quantities it may be less, and the assertion that it can be purchased by the ton at $8 will be assumed, for the purposes of this estimate, as correct,

making the cost of carbonic acid, as stated, 2.8 cents per pound.

The density of this gas at atmospheric pressure is 1.524, air being 1; and 8.5 cubic feet therefore will make one pound, and 43.89 pounds will give a volume of 375 cubic feet.

The highest pressure at which steam, air, or gas can be used to advantage upon the piston of an engine is about 14 atmospheres. If higher pressures are developed, they must be reduced to about 210 pounds before admission to the cylinders, as has been shown.

375 cubic feet condensed to 14 atmospheres = 27 cubic feet.

Now, if 27 cubic feet of gas were admitted to a cylinder 27 feet long, to act on a piston of 1 square foot area and cut off at $\frac{1}{14}$ of the stroke, the gas would be used in the most economical manner to secure foot-pounds of work, and the number of foot-pounds, at each stroke, would be found by multiplying the area of the piston by the average pressure ($210 \times .260$) and by the length of stroke, 27. Thus, $144 \times 210 \times 0.260 \times 27 = 212{,}274$ foot-pounds.

But 1 thermal unit = 772 foot-pounds, and $212{,}274 \div 772 = 275$ thermal units of work developed in each stroke.

27 cubic feet cut off at $\frac{1}{14}$ will be sufficient for 14 strokes, and the 43.89 pounds of carbonic acid will therefore develop $275 \times 14 = 3850$ units, at a cost of $1.24.

But 1 pound of coal will develop in combustion over 13,000 units, at a cost of 2½ mills per pound, at $5 per ton; therefore, 1 pound of coal will produce a mechanical effect, at a cost of 2½ mills, 3.37 times greater than the

44 pounds of carbonic acid, at a cost of $1.24. In other words, it would require 148.28 pounds of carbonic acid gas, costing $4.18, to produce the same mechanical effect in foot-pounds as could be obtained from the combustion of 1 pound of coal, costing 2½ mills.

Instead of being an economical source of power, the gas would cost nearly 1700 times as much as the coal, measured by the mechanical effect produced.

The same article stated that the gas could be collected, compressed, and used over again. It would be practically impossible to collect it, and if it could be collected no advantage could be gained, as it would be impossible to obtain from the gas, when compressed, an amount of units equal to more than half that expended in the compression. Air is the only gas that is suitable for compression as a motive power, and air costs nothing.

Such schemes for producing power as that which has been considered would be unworthy of notice were it not that many persons are deceived by plausible representations and induced to contribute money for development, resulting in serious losses through ignorance of the natural laws upon which such operations are dependent.

XVI.

TRANSMISSION OF POWER BY MEANS OF PIPES.

THE use of compressed air as a substitute for steam in the production of power requires its transmission often to very considerable distances, and the losses in transmission become an important subject for determina-

tion. Unlike steam, there is no loss by condensation whatever may be the distance to which the air is carried; or if pipes and reservoirs are tight there is no loss, however long the air may remain unused.

Having been employed professionally to investigate and report upon the practicability of the transmission of steam for heating purposes by the system of Birdsell Holly, of Lockport, N. Y., the writer discovered, in the course of experiments and observations, that a relation existed between the discharges of elastic and inelastic fluids, such that the discharges of any elastic fluid, as air or steam, could be readily determined from the discharge of water under like conditions, and the law which defines the relations between water and any elastic fluid may be thus enunciated:—

The discharge of elastic fluids through long pipes is equal to the corresponding water discharge under like conditions multiplied by the square root of the number which expresses the relative density as compared with water, and the product multiplied again by the square root of the initial density in atmospheres. The result will give the volume of discharge under atmospheric pressure.

As the subject of the transmission of elastic fluids through pipes is of interest and importance in connection with the use of compressed air for power, and especially for the transmission of power to operate motors on extended lines, a few pages devoted to the consideration of this subject and to the demonstration of the law that has been enunciated will not be considered inappropriate.

Discharge of Fluids Through Orifices.

The velocity acquired by a body falling freely in vacuo is eight times the square root of the height, both the velocity and height expressed in feet and time in seconds.

The velocity of fluids escaping through an orifice follows the law of falling bodies, and is expressed by eight times the square root of the height in feet.

This result is not practically correct, as the discharge is less than would be due to the full area of the orifice. The particles in escaping reduce the diameter by contraction of vein to 0.8, and the area to about 0.64 of the full area of the orifice.

In the case of elastic fluids the density of a vertical column would diminish from the bottom to the top, and the height, in estimating the volume of discharge, must be taken as that of a column of uniform density, the height of which would be equal to the pressure at the orifice.

Where the discharge is made into a receiver containing the same fluid at a reduced pressure, the differences in pressure must be taken in determining the height and velocity.

A remarkable exception to this law has been announced in a work on steam, published in London, 1875, by D. K. Clark, in which it is stated that the application of the formula for gravity is limited to cases in which the resisting pressure does not exceed about 58 per cent. of pressure which causes the flow. The flow is neither increased nor diminished by reducing the resisting pressure below about 58 per cent. of the abso-

lute pressure in the boiler. For example, the same *weight* of steam would flow from a boiler under a total pressure of 100 pounds to the square inch, into steam of 58 pounds total pressure, as into the atmosphere.

The author states that for this remarkable discovery he is chiefly indebted to the experiments made by Mr. R. D. Napier, and refers to a report on safety-valves made to the Institution of Engineers and Ship-builders in Scotland in 1874.

Desiring to obtain further information on this subject, I requested Prof. Geo. W. Plympton, former editor of *Van Nostrand's Engineering Magazine*, to see if he could find, in the libraries in New York, the report on safety-valves referred to. In a letter received in reply, he stated that he found the report at the rooms of the Society of Civil Engineers, but that it merely quoted the deductions of the experimenter, Napier, in the same form as previously given. Prof. Plympton also stated that Rankine discussed the same subject, and that Napier contributed articles to *Engineering* on this topic in 1872.

If the conclusions of Napier be accepted as correct, it would appear that steam escaping from an orifice into the air at a pressure of 25 pounds, acquires a velocity of about 800 feet per second, and attains a maximum of 875 feet, after which the velocity remains constant, however great the pressure. Some direct experiments on the velocity of steam escaping from an orifice, just completed by Messrs. Holly and Gaskill, of Lockport, give, in one case, 951 feet per second, and in another 1023 feet per second.

It is not difficult to understand that the *velocity* might be constant, for the velocity is that due to the height of a column of uniform density whose weight is equal to the pressure. Now, if the pressure should be doubled, the density and weight of a uniform column would also be doubled, and the height which determines the velocity would remain constant; but the declaration that the *weight* of steam discharged remains constant requires confirmation.

The efflux of steam through an orifice fortunately has but little influence on the discharge through long pipes where the velocities are comparatively low, and the results will not be affected by any uncertainties in regard to the velocity of flow through orifices.

Resistance of Long Pipes to the Flow of Elastic Fluids.

This was one of the most important subjects connected with the practical and extended application of the Holly system, and one upon which comparatively little information could at that time be obtained from books. Mr. Holly stated that he had searched in vain for any reliable information on the subject, and the only table found published was headed, "friction of air, steam, and gas in long pipes," without any recognition of the influence of density, which would cause the results to vary in the wide range of from 4 to 10. It is proposed, therefore, to give this subject careful consideration.

When engaged in maturing plans for tunnelling the Hoosac mountain, the writer made a series of experiments on the friction of air in a tunnel at Wiconisco.

A pipe of wood was constructed about 1400 feet long and 110 square inches in area. The current of air was produced by a vacuum fan, driven by a steam engine, the velocities determined by an electrical apparatus, and the results demonstrated :—

1. That the resistance was in proportion to the square of the velocity.

2. That the resistance was inversely as the diameter.

3. That the power required to pass a given quantity of air through pipes of different diameters was inversely as the fifth powers of the diameters. As a consequence, it was found that it would require a million times more power to pass the same quantity of air through a pipe one foot in diameter than would be required if the pipe were 10 feet.

At the Mt. Cenis tunnel it was decided to use compressed air as a motor, and the preparatory experiments were made at government expense by a commission of gentlemen of eminent scientific attainments, consisting of Messrs. DeNerache, Giulio, Menebrea, Rura, and Sella.

Special experiments were instituted on long lines of metallic pipe, continued by rubber hose, and observations made on pressure and velocity. The elastic force of the fluid was ascertained at the commencement and end of the pipe, and a curve traced for the interpretation of the results, from which a table was prepared, giving initial velocities in metres per second, diameters of pipes in decimals of a metre, and friction, or loss of tension in millimetres of a column of mercury.

A copy of the report of this commission was procured through the kindness of Professor Gillespie; from it a

table was calculated in which pressures were expressed in pounds, velocities in feet per second, and lengths in miles.

In using tables for the friction of elastic fluids through pipes, one peculiarity is observable. With dense fluids, such as water, the head is an important element in calculating the loss by friction, but with elastic fluids the initial velocity is given and the head is not a necessary datum in the calculations where there is a free discharge; but when there is back pressure it would seem that the initial density, as also the initial velocity, must be considered.

The explanation is this: Suppose pressure should be quadrupled, the fluid being supposed perfectly elastic would be quadrupled in density, and the power required to move it at a given velocity which measures the resistance would be quadrupled also, or would be as 1 to 4; but the velocity, being as the square root of the head or pressure, would be doubled also by quadrupling the head or pressure, and would be as 1 to 2, and the resistance would be $(1)^2 : (\frac{1}{2})^2$, or $\frac{1}{4}$. Hence, while the increase of density would quadruple the resistance, the reduction of velocity due to that pressure would reduce it to one-fourth, or the resistance of a given length with a given velocity would be constant.

This conclusion may be reached by another process of reasoning: Where a fluid is discharged through a long pipe the pressure at the commencement is the head in the reservoir; at the end where it discharges it is nothing, or simply the head due to the velocity. The hypothenuse of a triangle, of which the base represents the length and the perpendicular the head, will be the

hydraulic gradient; and so long as head divided by length or hydraulic gradient is constant, the velocity is constant and the discharge also. Now, if head should be quadrupled, velocity remaining constant, length must be quadrupled also, and head divided by length, which represents the friction per unit of length, will be constant also, and will vary in the same pipe with the square of the velocity.

In determining the resistance of different elastic fluids, density is an important element, which appears sometimes to have been overlooked. That it is important will be obvious from the consideration that the power required to move a body is in proportion to the weight of the body moved, and the weight is in proportion to density; if density should be doubled the resistance will be doubled, and if reduced the resistance will be reduced proportionately.

Let us imagine two elastic fluids of equal height, but whose densities compare as 1 to 2. As the heights are equal, the velocities of discharge will be equal. On a line as above, representing a unit of length, draw a perpendicular, 1, and complete the triangle; draw a second perpendicular, 2, and complete the second triangle. The perpendiculars at any point will represent the pressure at that point, and the areas of the triangles will be proportioned to the total resistance. As these areas compare as 1 to 2, so will the loss by friction be as 1 to 2, or as the densities.

The following are extracts from the report on the Holly system :—

DEMONSTRATION OF THE LAW OF THE DISCHARGE OF ELASTIC FLUIDS THROUGH LONG PIPES.

The quantity of steam discharged through a pipe of a given length and diameter under a given pressure, and the losses by friction and radiation, are questions which lie at the very foundation of the successful application of the Holly system, and without which it will be impossible to form plans and prepare estimates for the supply of any given district, with confidence that mistakes will not be committed, that the plans provided will not prove insufficient, and that mains will not require to be torn up or duplicated after the lesson has been learned from dearly-bought experience that sound theory should have taught in advance.

As it has been found impossible to procure from any known authors on hydraulics or pneumatics just that practical information that will meet the requirements of the present investigations, and as the writer has ventured to enunciate a fundamental law on which the solution of all problems relating to steam transmission must depend, and which is not only not contained in books, but is in conflict with rules given by some popular authors, no apology will be necessary for the time and space devoted to a demonstration of the law in question. This law may be thus enunciated :—

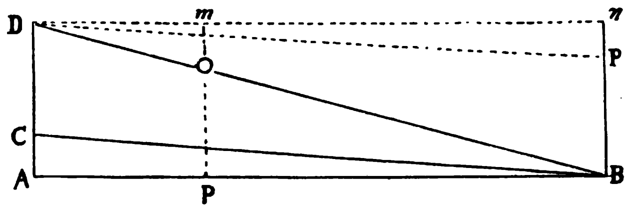
The discharge of steam, air, or any elastic fluid, under pressure through long pipes and at the volume due to atmospheric tension, is equal to the water discharged under like conditions multiplied by the square root of the number which expresses the relative density at atmospheric tension, as compared with water, multiplied

also by the square root of the initial pressure in atmospheres.

For example, air is 836 times lighter than water under ordinary atmospheric tension, and if n = number of atmospheres of initial pressure, then the water discharged, as determined by the usual formula, multiplied $\sqrt{836} = 29$ multiplied by $\sqrt{n}$, will give the discharge of air; and if the discharge of steam is required the multiplier will be $\sqrt{1712} = 42 | \times \sqrt{n}$.

If, then, n should be 4 atmospheres *total*, including atmospheric pressure, the difference of head to be used in the determination of the water discharge would be 3 atmospheres, and water discharge $\times\ 42 \times \sqrt{4}$ = water discharge $\times$ 84 = discharge of steam.

In like manner, if the total pressure should be 9 atmospheres = 120 pounds indicated pressure, the discharge of steam would be = water discharge $\times\ 42\sqrt{9}$ = 126 times the water discharge under an equal head.



And, in general, if w = the water discharge under any given head, length, and diameter of pipes, d = ratio of density of any elastic fluid, as compared with water and at the volume due to atmospheric tension, and n = number of atmospheres of initial pressure, then will the discharge, as compared with water, and at the volume due to atmospheric tension, be $= w \times \sqrt{nd}$.

Let A B represent a pipe of any given length, say one mile, and A C represent the pressure, say 60 pounds. The discharge of water at B, in cubic feet per second, is given by the formula :—

$$G = .0762 \sqrt{d^5} \sqrt{\tfrac{H}{L}}$$

d = diameter in inches, H = head in feet, or the difference in head when discharging against a lower pressure, and L = length in feet.

If A C = 60 pounds, the head of water would be $60 \times 2.31 = 138.6$ feet, and the discharge with a constant length would be as $\sqrt{H}$, or as $\sqrt{138.6}$, and the area of a triangle of which A B is the base and $\sqrt{138.6}$ = the altitude, would be proportionate to the water discharge or A B $\times \sqrt{138.6}$.

Now suppose that the fluid discharging at B should be steam instead of water under 60 pounds indicated pressure, the actual pressure would be 75 pounds, the number of atmospheres 5. The initial density five times that of steam under atmospheric pressure, or $\frac{1712}{5} = 342$, and the head due to a pressure of 60 pounds $= 138.6 \times 342 = 47{,}401$ feet.

The discharge being proportioned to the square root of the head, would be as $\sqrt{138.6 \times 342}$, or as $\sqrt{138.6}$ $\sqrt{\frac{1712}{5}}$ and if A B as before = base of a triangle, and 47,401 = altitude, the discharges being as the square root of the altitude, will be as the area of a triangle whose base is A B and altitude =

$$\sqrt{47401} = \sqrt{138.6} \times \sqrt{1712} \div \sqrt{5}.$$

The water discharges and steam discharges being as the areas of these triangles having the common base A B,

will compare, as $\sqrt{138.6}$ is to $\sqrt{138.6}\ \sqrt{1712} \div \sqrt{5}$, or if the water discharge be taken as unity, then as 1 is to $\sqrt{1712} \div \sqrt{5}$.

But this expression gives the discharge under initial density, and if the discharge is required at atmospheric tension, which is always desirable for the sake of uniformity, the result must be multiplied by 5, and the expression becomes $\sqrt{1712} \times 5. \div \sqrt{5} = \sqrt{1712} \times \sqrt{5}$, as previously stated, or generally as $\sqrt{n\,d}$.

The head due to velocity has not been considered, as in questions relating to discharges through long pipes it is so insignificant as compared with the head due to friction, that it may safely be neglected. It would not exceed, generally, a small fraction of a pound; but if great accuracy is desired the head, in feet, is readily determined, and is $\frac{v^2}{64}$ in which $v =$ initial velocity, and the head divided by the number of feet at initial density required to make one pound, will give the pressure in pounds required for this velocity v, which is in addition to friction. Suppose the length of the pipe should be increased, and draw a line from D to the end of the pipe, intersecting the line n B at P. The triangle D n P will be cut off, the perpendiculars of which will represent the loss of head by friction, and the square root of the area, the discharge in cubic feet, and the same rule holds good if the length should be less than A B.

Important Observation.—Although almost self-evident yet, as very erroneous ideas seem to have been entertained in regard to the friction of pipes, it is necessary to state, emphatically, that in the discharge of fluids

through pipes—whether the fluids be elastic or non-elastic—the *whole* of the head, less that due to velocity, is absorbed by friction; and where there is a free discharge there is no pressure whatever at the open end of the pipe.

Referring again to the diagram, if A B is a pipe a mile long and discharges water, steam, or air freely at B under an initial pressure at A = 60 pounds, there will be no indicated pressure whatever at B unless the discharge be throttled, and the reduction of pressure from A to B will follow the line of the hypothenuse, and the pressure at any point will be represented by the perpendicular. If, for example, the initial pressure be represented by A D, the pressure at B will be *o*, the total loss of pressure by friction in the distance A B will be 60 pounds. At any point P the pressure will be represented by the perpendicular O P, and the loss of pressure by O *m*.

But if the pipe is not discharging freely at B, the conditions will be very materially changed, and a large percentage of the fluid may be drawn off at intermediate points without affecting very seriously the pressure at B, due to the initial head if the pipe were closed.

It has been asserted as the result of observation that at Detroit a mile of pipe 6 inches in diameter was laid, and notwithstanding the fact that a large number of consumers were using steam at intermediate points, the pressure at the boiler and at the end was precisely the same; and the inference deduced therefrom was that steam can be carried almost any distance with a loss of power that is scarcely appreciable.

This is a great mistake, and it would be a fatal error

if works were planned and constructed with any such ideas. If the observed pressures at the two ends of the pipe at Detroit were the same, it resulted from two causes: First, a want of sensitiveness in the gauges, which often do not indicate within ten pounds of the correct pressure; and second, the intermediate consumers were drawing off a small percentage of the capacity of the pipe.

I will endeavor to elucidate this subject by a simple and practical illustration:—

Suppose a pipe be taken 6 inches diameter, one mile long, and 60 pounds initial pressure. The water discharge will be 1.1 cubic feet and the steam discharge $= 1.1 \sqrt{1712} \times \sqrt{5} = 102$ cubic feet of steam per second.

A horse-power for steam heating purposes has been taken as one cubic foot of water evaporated per hour, and one cubic foot of water $= 1712$ cubic feet of steam. Therefore, $1712 \div 3600 = 0.472$ cubic feet per second $=$ one horse-power.

And $102 \div 0.472 = 216$ horse-power $=$ maximum capacity of 1 mile of 6-inch pipe under 60 pounds pressure.

But suppose the end B of the pipe is closed, and at the point P $= \frac{1}{4}$ of a mile from A, one-fourth of the whole capacity of the pipe is drawn off, how will the pressure at B be affected?

If discharging freely at B, the pressure at P, at $\frac{1}{4}$ A B will be $\frac{3}{4}$ of 60 pounds, or 45 pounds, and the loss of pressure will be represented by O $m = 15$ pounds. But if the end B is closed, and the discharge at P is $\frac{1}{4}$ capacity of pipe, then the velocity from A to P will be reduced to $\frac{1}{4}$, and the friction, which is as the square of the velocity to $(\frac{1}{4})^2 = \frac{1}{16}$, and the loss of head from

taking off 25 per cent. of the whole capacity of the pipe at P would be $15 \times \frac{1}{16} = \frac{15}{16}$ of one pound, and the pressure at B would be $59\frac{1}{16}$ pounds as compared with an initial pressure of 60 pounds.

If one-half the whole capacity of the pipe should be drawn off at the middle point, or if there should be an equivalent thereto discharged the reduction of pressure at the extreme end, instead of being 30 pounds, or one-half, would be $\frac{60}{2} \times (\frac{1}{2})^2 = 7\frac{1}{2}$ pounds, and the pressure remaining would be $52\frac{1}{2}$ pounds.

These results, deduced from purely theoretical considerations, seem to be entirely consistent and reasonable; but it is important to test them by actual and careful experiments.

The experiments of Mr. Holly and Mr. Gaskill at Lockport were made under circumstances peculiarly favorable to accuracy. A large engine cylinder was used as a meter; the contents, including clearance, were 8.64 cubic feet; the number of cylinders discharged per minute, 66; cubic feet per minute, 570; distance from boiler equivalent to 168 feet of 2-inch pipe in frictional resistance; boiler pressure, 50 pounds; cylinder pressure, 30 pounds; loss by friction, 20 pounds.

From these data let us determine the friction in one mile of 6-inch pipe under a head or pressure of 60 pounds.

If Mr. Holly gets a discharge of 570 cubic feet per minute in a pipe 2 inches diameter and 168 feet long, the discharge per second will be $570 \div 60 = 9.5$, under total initial pressure of $50 + 15 = 65$ pounds; as the discharge is in proportion to the square root of the length, the discharge in one mile $= 9.5 \times \sqrt{\frac{168}{5280}} = 1.78$ cubic feet.

If the discharge is 1.78 cubic feet in a 2-inch pipe, the discharge being as the square root of the fifth power of the diameter, it will be in a 6-inch pipe $1.78 \times 15.6 = 27.76$. If the discharge be 27.76, under 30 pounds, and under initial pressure of 50 pounds, the discharge at atmospheric tension under initial pressure of 60 pounds, would be $27.46 \times \frac{30+15}{15} \times \sqrt{\frac{60}{50}} = 91.6$ cubic feet per second, as deduced from experiment of Messrs. Holly and Gaskill through a pipe obstructed by several bends.

We will now examine what should have been the discharge through a pipe one mile long, six inches diameter, under 60 pounds head, as deduced from the theoretical law heretofore enunciated.

The water discharge is 1.1 cubic feet per second, and $1.1 \times \overline{1712} \times \sqrt{\frac{60+15}{15}} = 102$, the theoretical discharge, and the difference, 10.6, is fully explained by the eight bends in the pipe through which the steam was transmitted in the experiment.

This result, giving a greater theoretical than actual discharge, is the more gratifying because it has generally been believed that theory was unreliable, and that the actual results as deduced from observation and experiment were far in excess of the capacity and pressure as given by the books.

This is true, because in stating a rule the books did not always state the conditions under which it was applicable, as, for example, the rule that the discharge of air is equal to $30\frac{1}{4}$ times the discharge of water under like conditions, is true only at one initial pressure, and that a very low one, while under high pressures the

error from its application may be several hundred per cent.

If theory is not sustained by observation and experiment, it only proves that the theory is defective, and that the true law has not been discovered; but that there are natural laws is unquestionable, and these laws, as applicable to pneumatics, are as immutable as those of gravity.

Practical men, proceeding without a knowledge of these laws, are like mariners at sea without chart or compass.

I propose to show that the law of discharge that has been here given is further verified by the careful and elaborate experiments made at the Mt. Cenis tunnel.

Friction of Air in Pipes as Determined from the Experiments at the Mt. Cenis Tunnel.

The scientific commission, appointed to conduct these experiments, reported the following table as a condensation of their results:—

Loss of Tension per 1000 *metres of Pipe, expressed in Millimetres of a Column of Mercury.*

Velocity of air at the entrance of the pipe, in metres, per second.	Diameter of pipes in the clear, in decimals of a metre.					
	0.10	0.15	0.20	0.25	0.30	0.35
1	6	4	3	3	2	2
2	26	18	13	11	9	8
3	62	42	31	25	21	18
4	108	72	54	44	36	31
5	167	112	84	67	56	48
6	233	156	117	94	78	67

An inspection verifies these laws :—

1. Friction inversely as diameters.
2. Friction directly as squares of velocities.

To which may be added two other laws :—

3. Friction directly as the length.
4. Friction directly as the density.

In comparison with other results the friction of 1 mile of 6-inch pipe with initial velocity, 20 feet will be deduced from this table.

Assume any number, say a pipe 0.2 of a metre diameter and 5 metres velocity, the loss in millimetres of mercury is 84.2 of a metre = 7.874 inches ; 5 metres per second = 16.4 feet ; 1000 metres = 3281 feet ; 1 millimetre = 0.03937 inches.

Then $84 \times \frac{7.874}{6} \times \frac{20^2}{16.4^2} \times \frac{.03937}{2} \times \frac{5280}{3281} = 5.1$ pounds, as the resistance of air, and for steam 2.5 pounds per mile, assuming loss of tension to be in proportion to density.

We will now apply the law as deduced from the hydraulic discharge :—

The discharge of water under a head of 60 pounds, length 1 mile and diameter 6 inches, is 1.1 cubic feet per second.

Air is 836 times lighter than water. 60 pounds $= \frac{60+15}{15} = 5$ atmospheres ; $1.1 \times \sqrt{836} \times \sqrt{5} = 67.87$ cubic feet per second, and at initial density $= 67.87 \div 5 = 13.57$ cubic feet, and initial velocity 68 feet per second, nearly.

Now, if the loss of tension with initial velocity of 68 feet be 60 pounds, the loss with velocity of 20 feet will be $60 \times \frac{20^2}{68^2} = 5.1$ pounds.

This is precisely the loss of tension in one mile of 6-inch pipe discharging air under an initial velocity of 20 feet per second, as deduced from the experiments of the Mt. Cenis Tunnel Commissioners.

The law of discharge, above stated, seems to be completely verified and established, both by the experiments in Europe and those made by Mr. Holly, at Lockport, with the engine metre, and I think can be safely relied upon as a basis of calculation of capacity of mains and losses by friction in transmission.

The following table will be convenient, giving the discharge of steam at the volume of atmospheric tension, the corresponding water discharge under same head, diameter and length being taken as unity, and pressures varying by half atmospheres from 1 to 10 :—

Pressure in Atmospheres.	Initial Densities.	Volume of Discharge.
1	1712	41.4
1½	1141	50.7
2	856	58.6
2½	685	65.5
3	571	71.7
3½	489	77.3
4	428	82.8
4½	381	88.2
5	342	92.5
5½	311	97.3
6	285	101.4
6½	263	105.9
7	245	109.6
7½	228	113.2
8	214	117.0
8½	201	120.5
9	190	124.1
9½	180	127.7
10	171	130.8

TABLE OF THOMAS BOX.

In the valuable work on heat by Thomas Box, is given a table for the friction of air, steam, and gas in long pipes. The difference in density is not recognized in this table, but it was probably intended for air, as this fluid was more particularly under discussion. Under this hypothesis, the results will be compared with our assumed standard of velocity, 20 feet, length one mile, diameter six inches.

The table gives the head to overcome friction with velocity of 10 cubic feet per minute through a two-inch pipe for a distance of one yard $=0.000162$ pound.

Area of 2-inch pipe $= 3.1416$ and $10 \times \frac{144}{3.1416 \times 60} = 0.77$ $=$ velocity in feet per second.

$0.000162 \times 1760 = 0.285120 =$ friction per mile in 2-inch pipe.

$0.285120 \times \frac{2}{6} = 0.09504 =$ pounds per mile friction in 6-inch pipe, velocity 0.77.

$0.09504 \times \frac{20^2}{.77^2} = 6.3 =$ friction of air in a 6-inch pipe for a distance of one mile and velocity 20 feet per second.

The friction of steam at atmospheric density should by the same rule be 3.15 pounds, which is in excess of the results deduced from formula, from the Mt. Cenis experiments, and from other experiments.

FORMULA OF WEISBACH.

Weisbach gives the following formula for the friction of air through long pipes :—

$f = 0.0256 \times \frac{l}{d} \times \frac{v^2}{2g}$ in which

l = length in feet;
d = diameter in feet;
v = velocity in feet per second;
f = height of a column of air equal to the resistance by friction.

To test this formula, assume length = 1 mile, diameter 6 inches or 0.5 of a foot, and v = 20 feet. Then friction of one mile represented by a column of air equals

$$0.0256 \times \frac{5280}{.5} \times \frac{20^2}{64} = 1700 \text{ feet.}$$

But 1700 feet of air, if at atmospheric tension, would be equivalent to about two feet of water, weighing less than one pound, while from other data, both theoretical and experimental, it is known that the friction is five pounds. If the initial, instead of the terminal, density is intended to be used, the difficulty is that there is no way given for the determination of this density, and the formula, even if correct, is practically useless.

So also the rule of the engineer's pocket-books, that the discharge of air is 30½ times the discharge of water under like conditions, is entirely fallacious. It can be true only at one pressure, and that a very low one, and it fails to recognize the varying densities of different elastic fluids under varying pressures, without which no rule can be reliable.

Pipes of Equivalent Resistances.

When a line of pipe consists of portions whose diameters are not uniform, it is necessary to make a correction by substituting the length of pipe of uniform diameter that would give an equivalent resistance.

It has been stated that where quantity is constant and diameter variable the friction is inversely as the fifth power of the diameter.

If the friction in one mile or one unit of length of one-inch pipe be taken as unity, the number of miles of pipe of any other diameter will be given by the following table, giving equal resistance :—

1 inch pipe	1.
$1\frac{1}{2}$ "	7.5
2 "	32.
$2\frac{1}{2}$ "	97.65
3 "	243.
4 "	1024.
5 "	3125.
6 "	7776.
7 "	16807.
8 "	32768.
9 "	59049.
10 "	100000.
11 "	161051.
12 "	248832.

FORMULA FOR CALCULATING TABLES OF LOSS OF HEAD BY FRICTION.

It has been seen that in the transmission of steam through a pipe six inches in diameter and one mile long the loss by friction was 2.5 pounds, with an initial velocity of 20 feet per second.

For any other length we have these laws :—

1. The friction is as the length.
2. The friction is inversely as the diameter.
3. The friction is as the square of the velocity.
4. The friction with different fluids is as the density.

As a basis of calculation, it will be convenient to determine the friction of steam in 1 mile of 1-inch pipe, with an initial velocity of one foot per second.

The friction in one mile of 6-inch pipe, and initial velocity 20, being 2.5 pounds with steam, the friction in a pipe 1 inch in diameter will be $2.5 \times 6 = 15$ pounds under the same velocity; and the friction with a velocity of 20 feet per second being 15 pounds, the friction with a velocity of one foot per second will be $15 \times \frac{1}{20^2} = 0.0375$.

For any other diameter or velocity the expression becomes:—

$$\text{Friction per mile} = 0.0375 \times \frac{v^2}{d}$$

The initial velocity must be determined from the discharge, and the terminal discharge, as previously stated, is = water discharge $\times \sqrt{1712} \times \sqrt{n}$, in which n = the atmospheres of pressure. This discharge divided by n gives discharge at initial density, and the discharge at initial density in cubic feet divided by the area in square feet will be initial velocity.

Table of Loss by Friction for Steam in Pounds per Square Inch for 1 *Mile of Pipe, with Initial Velocities as Given in the First Column in Feet per Second, and Diameter of Pipes from* 1 *to* 12 *Inches.*

Velocity Ft. per sec.	Diameter of Pipes in Inches.													
	1	1½	2	2½	3	4	5	6	7	8	9	10	11	12
5	.9375	0.625	.468	.375	.312	.2344	.1875	.156	.134	.117	.104	.094	.085	.078
10	3.75	2.50	1.875	1.50	1.25	.937	.75	.625	.535	.468	.42	.375	.341	.312
20	15.0	10.0	7.5	6.0	5.0	3.75	3.0	2.50	2.14	1.87	1.66	1.50	1.36	1.25
30	33.75	22.50	16.87	13.5	11.25	8.44	6.75	5.62	4.82	4.22	3.75	3.37	3.07	2.86
40	60.0	40.0	30.0	24.0	20.0	15.0	12.0	10.0	8.55	7.5	6.66	6.00	5.46	5.00
50	93.75	62.5	46.87	37.5	31.25	23.44	18.75	15.62	13.4	11.72	10.42	9.37	8.52	7.81
60	135.0	90.0	67.5	54.0	45.0	33.75	27.0	22.5	19.3	16.87	15.0	13.5	12.3	11.25
70	184.0	123.	92.0	73.6	61.3	46.0	36.8	30.6	26.3	23.0	20.4	18.4	16.7	15.3
80	240.0	160.	120.	96.0	80.0	60.0	48.0	40.0	34.3	30.0	26.6	24.0	21.8	20.0
90	304.0	203.	152.	121.6	101.3	76.0	60.8	50.6	43.4	38.0	33.7	30.4	27.6	25.3
100	375.0	250.	187.5	150.0	125.0	93.7	75.0	62.5	53.6	46.8	41.6	37.5	34.1	31.2
125	586.0	391.	293.	234.4	195.3	146.5	117.2	97.6	83.7	73.2	65.1	58.6	53.3	48.8
150	843.0	562.	421.	337.2	281.0	210.7	168.6	140.5	120.4	105.3	93.6	84.3	76.6	70.2
175	1148.	765.	574.	459.1	382.6	287.0	229.6	191.3	164.0	143.5	127.5	114.8	104.4	95.6
200	1500.	1000.	750.	600.0	500.0	375.0	300.0	250.0	214.3	187.5	166.6	150.0	136.3	125.0
250	2343.	1562.	1172.	937.2	781.0	585.7	468.6	390.5	334.7	292.8	260.3	234.3	213.0	195.2
300	3375.	2250.	1687.	1350.	1125.	843.7	675.0	562.5	482.1	421.8	375.0	337.5	307.0	281.2
350	4593.	3062.	2296.	1837.	1531.	1148.	918.6	765.5	656.1	574.	510.3	458.3	417.6	382.7
400	5000.	3333.	2500.	2000.	1666.	1250.	1000.	833.0	714.3	625.	555.5	500.	455.5	416.5

For any other diameters or velocities observe :—

1. The friction is as the square of the velocity.
2. The friction is inversely as the diameter.
3. The friction is directly as the length.
4. The friction with other elastic fluids is directly as the density.

Capacity of Mains and Velocity of Steam.

The discussions in the preceding pages will indicate a manner of obtaining the discharge of any elastic fluid through pipes, and, as a consequence, its velocity when the diameter is known. It is only necessary to calculate the water discharge under the same length, diameter, and pressure, and multiply the result by the square root of the number expressing the relative density, multiplied by the square root of the number of atmospheres of initial pressure.

The limit of velocity is found in the discharge through an orifice, or short pipe of not more than two diameters, and appears from the experiments of Messrs. Holly and Gaskill to attain its maximum at about 1000 feet per second, between which and zero the velocity will vary with pressure, diameter, and length.

Assuming a maximum effective pressure of 60 pounds per square inch in the mains, equal to 75 pounds absolute or 5 atmospheres, the water discharge in a six-inch pipe 100 feet long will be, per second: cubic feet $= 0.0762\sqrt{6^5 \times \frac{60 \times 2.31}{100}} = 7.85$ cubic feet, and $7.85 \times \sqrt{1700} \times \sqrt{5} = 7.85 \times 41.3 \times 2.24 = 726$ cubic feet, and $726 \div 0.2 \times 5 = 726 =$ initial velocity of the steam on entering the pipe.

If the length of pipe were 1000 feet, the discharge and the velocity would be reduced in proportion of $\sqrt{\frac{100}{1000}}$ or $\frac{726}{3.17} = 229$ feet per second.

The general formula for the discharge of steam is, in cubic feet, per second, at atmospheric density :—

$c = 0.0762 \sqrt{d^5} \times \sqrt{\frac{H}{L}} \times 41.3 \times \sqrt{p}$; or $c = 31.47 \sqrt{d^5} \times \sqrt{\frac{H}{L}} \times \sqrt{p}$, in which $d =$ diameter in inches.

H = head, in feet of water.

L = length in feet.

p = density in atmospheres.

If it be found most convenient to express the pressure in pounds, instead of feet of water, the constant 31.47 will become 47.73, and H will then represent pounds of effective pressure.

The following table, calculated from the above formula, will facilitate computations on the capacity of mains for the transmission of steam, and the same table may be used for air by multiplying by $\sqrt{\frac{836}{1712}} = \frac{289}{414} = \frac{3}{4}$, nearly.

Diameters inches.	Square root of 5th powers.	Area of pipe in square feet.	Discharges of Steam in Cubic Feet per Second for a Length of 100 Feet, at Atmospheric Density, under Initial Pressure in Pounds of											
			5	10	15	20	25	30	35	40	45	50	55	60
1	1	$\frac{1}{183.}$	1.235	1.948	2.637	3.274	3.899	4.561	5.183	5.692	6.420	7.036	7.661	8.320
$1\frac{1}{2}$	2.74	$\frac{1}{81.5}$	3.384	5.337	7.251	9.003	10.723	12.542	14.254	15.653	17.655	19.349	21.067	22.880
2	5.66	$\frac{1}{45.8}$	7.000	10.039	14.883	18.552	26.093	25.846	29.370	32.255	36.380	39.871	43.411	47.147
$2\frac{1}{2}$	9.88	$\frac{1}{29.3}$	10.979	17.318	23.443	29.106	34.652	40.567	46.077	50.602	57.074	62.550	68.106	73.965
3	15.6	$\frac{1}{20.3}$	19.266	20.389	41.137	51.074	60.824	71.151	80.855	88.795	100.14	109.76	119.51	129.79
$3\frac{1}{2}$	22.9	$\frac{1}{14.9}$	27.40	44.58	60.39	74.97	89.27	104.4	118.7	130.4	147.0	161.1	175.4	190.5
4	32.0	$\frac{1}{11.46}$	39.68	62.40	84.16	104.64	124.8	145.9	165.8	172.1	205.4	225.3	245.1	266.2
$4\frac{1}{2}$	43.0	$\frac{1}{9.08}$	53.11	83.74	113.4	140.7	167.6	196.1	222.9	244.8	276.0	302.5	333.7	357.7
5	55.9	$\frac{1}{7.33}$	69.03	108.8	147.4	187.2	218.0	255 0	289.8	318.2	358.9	393.3	434.9	466.1
6	88.2	$\frac{1}{5.09}$	108.9	171.8	232.6	288.7	343.9	402.3	457.2	502.2	566.3	620.6	684.6	730.9
7	129.7	$\frac{1}{3.74}$	160.2	252.6	342.0	424.5	505.6	591.5	672.3	738.3	832.6	912.5	1007.	1079.
8	181.0	$\frac{1}{2.86}$	223.5	352.6	477.4	592.4	705.7	825.5	938.3	1031.	1162.	1284.	1405.	1506.
9	243.0	$\frac{1}{2.25}$	300.1	473.3	640.8	795.3	947.4	1108.	1260.	1383.	1560.	1710.	1886.	2032.
10	317.	$\frac{1}{1.85}$	391.5	617.5	836.0	1038.	1236.	1446.	1643.	1805.	2035.	2230.	2461.	2638.
11	401.	$\frac{1}{1.52}$	494.	779.2	1054.8	1309.	1559.	1824.	2073.	2277.	2568.	2814.	3064.	3328.
12	499.	$\frac{1}{1.273}$	617.	974.	1318.	1637.	1949.	2280.	2591.	2846.	3210.	3518.	3830.	4160.

For any other length than one hundred feet, divide the numbers in the table by the square root of the length in feet, and multiply by ten.

For discharges at initial densities, divide the numbers in the table by the pressures in atmospheres.

For initial velocities, divide the discharge at initial density by area in square feet, the quotient will give feet per second.

Evaporation of Water under Pressure.

A diversity of opinion is found to exist amongst practical engineers and boiler manufacturers in regard to the effects of increased pressure upon evaporation ; some contending that the quantity of water evaporated under high boiler pressures is greatly reduced—others that the difference is inconsiderable, and others again admit that the question is new to them and has not received attention.

The fact of a difference of evaporation under pressure is very generally admitted by mechanical engineers, and is moreover confirmed by direct experiments in England, where, as the result of 28 carefully conducted experiments, it was found that the coal required to evaporate 20 cubic feet of water at pressures from 0 to 60 lbs. above atmosphere varied from 195 to 210 lbs., or a difference of 8 per cent with 3 atmospheres.

No explanation of this fact, so far as the writer knows, has been attempted, but it would seem reasonable to assume that the consumption of coal should be in proportion to the work done.

If we suppose one cubic foot of water to be confined

in a cylinder of one square foot sectional area and of indefinite height, and heat applied to convert the water into steam under the atmospheric pressure of 14.7 pounds, the space through which this weight would move would be 1700 feet, and $1700 \times 14.7 \times 144 = 3,598,560$ foot-pounds of work in the conversion of one cubic foot of water into steam under one atmosphere of pressure.

Assume as a second illustration that the pressure is 200 lbs., the temperature will be 387 degrees, and the space occupied by the steam under this pressure 158 cubic feet. The foot-pounds of work in the conversion of the water into steam under this pressure will be 4,550,000, an increase of 951,440 foot-pounds, or 26 per cent.

The following table of evaporation is based on the Lockport duty of 9 lbs. water to 1 pound coal under 25 lbs. pressure, and assumes that the consumption under any other pressure is in proportion to foot-pounds of work.

Column 1 represents total pressure of steam.
" 2 " temperature.
" 3 " cubic feet steam from 1 cubic foot water.
" 4 " foot-pounds of work in expanding.
" 5 " pounds of water evaporated by 1 lb. coal.

1	2	3	4	5
14.7	212°	1700	3598560	9.783
20	228	1281	3689000	9.542
25	241	1044	3759000	9.364
30	252	883	3815000	9.227
35	261	767	3866000	9.116
40	269	679	3911040	9.000
45	276	610	3963000	8.850
50	283	554	3989000	8.825
55	289	508	4024000	8.748
60	295	470	4061000	8.668
65	301	437	4079000	8.628
70	306	408	4097000	8.592
75	311	383	4115000	8.553
80	316	362	4133000	8.516
85	320	342	4151000	8.481
90	324	325	4169000	8.444
95	328	310	4178000	8.426
100	332	292	4205000	8.370
110	339	271	4293000	8.201
120	341	251	4338000	8.126
130	352	233	4362000	8.070
140	357	218	4395000	8.015
150	363	205	4428000	7.950
175	376	178	4486000	7.847
200	387	158	4550000	7.742

Steam Required per Horse-power.

It is customary for parties using power to furnish other parties with steam for a consideration, and the charge made in Philadelphia varies from $75 to $125 per horse-power per annum.

This is a very uncertain basis of charge, for the steam consumed per horse-power is a very variable quantity, being dependent on the degree of expansion in the cylinder.

If steam is used at a low pressure and without expansion, it requires fully one cubic foot of water evaporated

per hour per horse-power, or 0.472 cubic foot per second, as can be readily shown. Suppose effective pressure = 20 pounds. The foot-pounds of effective work in evaporating one cubic foot would raise 144 × 20 = 2880 pounds to a height of 767 feet in one hour, or 36,800 foot-pounds per minute, which is slightly in excess of a horse-power. At lower pressures a cubic foot of water evaporated would produce less and at higher pressures more, assuming that the steam is used without expansion in the engine cylinders. Now, suppose steam to be used expansively. In this case half a cubic foot of water per hour would furnish a horse-power, or 3½ pounds of coal. At this rate the margin of profit in supplying power would be very large to a company with numerous patrons, and at the same time it might prove quite economical to the consumer. If higher pressures and greater expansion could be used, the economy would be still greater.

XVII.

GENERAL SUMMARY.

The fact that the published reports of street railway companies give but little information by which the relative economy of the different systems can be compared is universally conceded. The reasons are obvious; the reports of cost of plant and of operation are based upon widely different conditions. A cable line, for example, requires an expenditure of sixty per cent. of the engine power at the central station to move the

cable alone, and this power must be expended whether there are two or two hundred cars upon the line. In one case the running expenses per car-mile may be ten or twenty times as great as in another. In fact, it is conceded that cable lines are adapted only to metropolitan localities with a heavy traffic, and that some other system must be used where the travel is moderate. It has been stated that the average travel on cable lines is about six times as great as on those operated by horse or trolley, but of course no general and invariable proportion can be established.

The only possible way in which a comparison can be made of the relative economy of different systems is by assuming that they are to be operated under similar conditions, the most important of which are, length of line operated and equal volumes of traffic. The assumed standard adopted has been 6 miles of double track and the car intervals two minutes.

In estimating the cost of plant neither a very high nor a very low estimate has been taken and it must be remembered that the absolute figures are not of very great importance; they affect chiefly the item of interest, and, being the same for all, do not seriously affect the comparisons of operating expenses.

Unable to procure desired information from published reports the author has interrogated officers of roads to ascertain the engine power at central station in proportion to length of line and volume of traffic and the percentage used in moving engines, dynamos, cables, motors and in transmission, but in no case has any very satisfactory information been obtained. If, then, operators who are familiar with any particular system, think that

they have discovered inaccuracies, it is hoped that due allowance will be made, and they can with their superior knowledge of individual cases make such corrections as the facts known to them will warrant. There has been no disposition to recommend any system more favorably than its merits deserve, or weaken confidence in any that seemed worthy of approval. To expose errors where natural laws have been violated, and where failure and pecuniary loss would be inevitable from the adoption of proposed systems in which such laws were ignored, seemed to be simply a duty.

Horse Cars.—Cars propelled by horse- or mule-power have presented the nearest approximation to uniformity in cost of operation, and such uniformity was to be expected. After eliminating the fixed charges the variable expenses of operation would be nearly in proportion to the number of cars on the line; in other words, in proportion to the car-miles; while in other systems dependent for power upon transmission by wires or cables from a central station, the cost of power per car will vary between very extreme limits dependent upon the number of cars upon the line.

The variations in horse-power are chiefly in the item of feed. The Chicago lines report cost of feed per horse per day 18.58 cents. The army rations for cavalry cost in the east 26 cents. The livery charge for feed and stable service is from 60 to 70 cents per horse per day. From the sources of information accessible the cost of operation per car-mile by horse-power has been taken at 24 cents, and an average of 5 passengers to a car would be required to pay expenses.

Steam Motors.—The determination of the consumption of fuel and the cost of repairs in small steam motors presented considerable difficulty from the fact that no records were accessible of the cost of operation of such motors, and the results from performances of standard locomotives on ordinary roads are of little value from the existence of widely different conditions. The traction of cars on a straight and level railroad is about 8 pounds per ton; of a train including locomotive about 9 pounds, but a street motor has a much worse track and smaller wheels, and the traction, although not readily determinable without direct experiment, is put at not less than 25 lbs. per ton and the cars 15 lbs. It is upon these resistances that calculations have been based.

Steam motors are objectionable on account of smoke, ashes, sparks, cinders, and noise from exhaust and are now rarely used.

Ammonia Motor.—An ammonia motor invented and patented by Dr. Emile Lamm was operated in New Orleans in 1871, and reported upon favorably by a committee of which General G. T. Beauregard was chairman.

The fact that ammonia when in a liquid state volatilizes at a very low temperature and produces a higher pressure at 50° than water at 320°, led to great expectations that practical experience did not realize.

It was conceded by Dr. Lamm that heat was the real source of power, and that it was impossible with a given quantity of heat to obtain more force with one element than with another. Comparisons must be made by taking into consideration the entire cycle of changes, and

although fluid ammonia would, in expansion into a gaseous state, develop enormous energy, yet in completing the cycle of changes by the reconversion of the gas into a fluid, an amount of calorific energy was required practically equal to that which had been expended in work in expansion, and therefore no advantage was gained over the ordinary steam engine.

The ammonia motor was abandoned because, as General Beauregard says, "The heated steam motor" was preferred "as being cheaper and less troublesome;" yet after 22 years the ammonia motor is now revived with claims of improvements that will render it a practical success. If so, experience in actual work must demonstrate the fact. Theory does not offer much encouragement to believe that a claim for superior economy over any other system can be established.

The Hot Water Motor.—A motor named the heated steam motor was used for some time upon the street railroad in New Orleans during the presidency of General Beauregard and abandoned by a subsequent administration in favor of mule power. The system has recently been revived under a different name and a company formed to secure public recognition and support. It was recently brought to the attention of and was discussed by the American Society of Civil Engineers, but the radical defect in the system does not appear to have been recognized, as seems from the published report of the discussion held by this very practical and scientific body.

The prominent feature in the hot water system is that the water is heated in a stationary tank to a high temperature, then transferred to a boiler on the motor and a portion of the water, converted into steam by reduction

of pressure, is used to move the pistons in the motor cylinders.

The defect of the system, and that which appears to have been overlooked by those who have attempted to make calculations of the length of run based upon the units of sensible heat contained in the hot water, consists in the fact that for every pound of water converted into steam 967 units become latent, and this amount of heat is taken from the water that remains, thus cooling it so rapidly that, instead of a run of 20 miles, as some have calculated, the motor would not run two miles.

In consequence of this difficulty the hot-water engine must be provided with a fire-box and fuel to generate steam when the water becomes too cold and the pressure runs low, and it thus becomes an ordinary steam motor presenting no special claims for public consideration.

If, for example, the motor should be started with water at a temperature of 356 degrees, giving a pressure of 146 pounds to the square inch, and run until the pressure should be reduced to 60 pounds, the sensible temperature would become 293 degrees, a reduction of only 63°; but in addition to this every pound of steam used within the cylinders would have carried off 967 degrees, approximately, as latent heat which is fifteen times as much as the thermometric difference in temperature, and thus the water in the motor is cooled so rapidly that only a very short run is possible without reheating. The failure to recognize this fact has led to errors in calculation that may disappoint expectations and lead investors into serious financial losses.

Gas Motors.—Theoretically the gas engine should convert into work the greatest number of heat-units of the

fuel consumed in its production. Instead of transmission from a generator to a motor cylinder, which always involves loss, the gas engine presents the peculiarity of combustion in the cylinder itself and in direct contact with the piston upon which the energy is to be expended. No other mode of application can secure a greater number of foot-pounds of work in proportion to heat-units developed.

Practically, however, there is considerable difference in the cost of the fuel required, which to a great extent neutralizes the theoretical advantage. Naphtha, which is the cheapest fuel that can be used in gas engines, costs five times as much per pound as the cheap coals that can be burned under stationary boilers, but can utilize twice as many units per pound. Fuel is not the most expensive item in the cost of operation, and there seems to be a possibility that gas motors may come into use to a considerable extent. They possess the advantage of being independent motors, not subject to interruption by derangement of central power station, cable, or feed wires. On the other hand, they present the disadvantage of requiring continuous operation with consumption of fuel when thrown out of gear and not running. Constant combustion of gas or vapor is necessary to keep up circulation of hot water to vaporize the naphtha. If this is not done, hot water must be drawn from a tank before the motor can be started. As in the case of the ammonia motor, experience may develop defects and the machines be found to be more troublesome and expensive than some other, but it is soon to be tested. Mr. Yerkes, the President of the West Chicago Street Railway Company, has ordered twenty gas motors for

use in that city. In his remarks at a recent annual meeting the statement was made that "it is the short haul and the people that hang on to the straps that pay the dividends." A suffering public has paid dividends long enough by hanging on to the straps, and means should be found to compel companies to provide reasonable accommodation.

In answer to a question in regard to the result of experiments with motors, President Yerkes said that all electrical and other motors for use on the outlying roads of the system had been discarded, and that the conclusion had been reached that a gas motor, which the company is now having manufactured, is the best thing in this line that the company has experimented with. The motor referred to is the Connelley.

Pneumatic and Compressed Air Motors.—More space has been given to the consideration of this subject than to any of the other forms of motors and systems of operation, for the reasons that it is the one upon which, in the mind of the public, the greatest ignorance prevails, and the one to the investigation of which the writer has devoted the greatest amount of time and attention.

The pneumatic motor presents the following advantages :—

It is the cheapest of all the systems in cost of plant and of operation.

It can run on any surface, elevated or underground tracks, and requires no trolleys or cables, no subterranean or overhead constructions.

The motors are all independent, so that no derangement of machinery at the central station can affect the

line. The engines and compressors being in a number of units, repairs to one will not affect the rest.

There are no live feed wires to shock or kill men or horses, or by contact with telephone or telegraph wires, to communicate fires to buildings or shocks to occupants.

There are no obstructions to the free use of fire apparatus.

There are no dynamos to be burned and disabled during electrical storms.

There are no broken strands of cable to entangle grip bars and cause wrecks of cars and accidents to street vehicles.

There is no necessity, as in gas motors, to keep the machinery in constant motion.

There is no loss, as in hot water, steam, or ammonia, by radiation or condensation, but the charge in a motor will remain until used.

There is no serious loss by transmission of the power from a central station even to a distance of miles.

The speed is practically unlimited except by municipal restrictions.

No paying space for passengers is occupied either by air reservoirs or motor machinery. The reservoirs are under the seats and the machinery under the floor.

There is a surplus of power to ascend grades or overcome extraordinary resistances of brief duration.

Extra cars can be provided to any extent required by the exigencies of the service without reducing the length of the run, as the trail cars can carry their own charges of air in reservoirs under the seats.

A street blockade, or detention from any other cause,

cannot reduce the capacity for propulsion. No reservoirs of fuel or water are required in transit, and the stored power remains intact until used, however long the period of suspension.

A peculiar feature of the Hardie motor not possessed by any other, so far as known, is that in descending grades, or whenever the motor cylinders are called into use as brakes, they act as air pumps, and, instead of using air, pump back an additional supply into the reservoirs.

The fuel required for a given amount of propulsive energy in pneumatic motors costs less than one-fourth as much as an equal amount in steam motors for similar service, and this cost is covered by seven mills per car mile.

Five of the Hardie pneumatic motors were in active daily use for several months on the Second Avenue street railroad in 1879, and furnished the data upon which the computations in this volume were based and the results determined. From such results, based on repeated daily observation, there can be no reason for withholding confidence.

The tests of the motor constructed for the Second Avenue Elevated Railroad in New York were certified to by the chief engineer of the Manhattan L Railroad, who is now engineer of the Chicago and South Side Railroad; by the former train-master of the Manhattan L Railroad and master mechanic of the Suburban Transit Company of New York, and now superintendent of the Chicago and South Side Rapid Transit Company, and by the foreman-machinist of the locomotive repair shop of the Second Avenue Elevated Railroad. These

certificates referred to the actual performance in hauling the regular passenger trains upon the Second Avenue Railroad making twenty-three station stops, and show that every requirement was fulfilled.

There was also an award of the medal of superiority by the judges of the American Institute in 1878. There was also an expression of entire confidence in the performance of the machine by Messrs. Burnham, Parry, & Williams of the Baldwin Locomotive Works, and a still stronger statement from Charles T. Parry, one of the firm, who considered the system not only practical, but particularly well adapted for use in cities and towns; he enumerated the advantages, and claimed superior economy in cost of repairs, as there was no excessive heat to burn out certain parts.

If a system can justly claim the possession of every advantage that could be considered desirable, free from any conceivable defect, and at the same time more economical than any other, why has it not been universally adopted?

The answers have been given. They will be briefly repeated.

The public was not ready for the adoption of the system in 1879. Presidents of horse-railroad companies were afraid to allow cars to run without horses in front, thinking that the horses in the street would scare, cause accidents, and that suits for damages would be instituted. Efforts to induce them to have experts make examination of the merits of the system proved fruitless, and were abandoned.

There was a general misapprehension in regard to the loss of power in compressing air, and directors of com-

panies could not be made to understand that this loss was compensated more than fourfold by economies in other directions.

But the principal difficulty arose from the fact that the men who formed the Pneumatic Tramway Company were neither capitalists nor practical men. They had secured a transfer of the patents from the inventor, Robert Hardie, for a stock consideration; had capitalized this stock at one million dollars, divided amongst themselves; they sold some shares to build five motors for street service; borrowed money to build the elevated railway motor at the Baldwin shops, could not pay the notes when due; lost the control of the patents, which became tied up in the estate of a deceased creditor, and the result was an abandonment of the entire enterprise. Hardie lost his patents, his stock became worthless, and he accepted the position of superintendent of a locomotive works, and has been working at a salary ever since.

This explanation will perhaps furnish reasons why the best system for either ordinary or rapid transit in cities has never been adopted on a practical scale in the United States, although an inferior pneumatic motor, the Mekarski, has been for many years in successful use in Europe.

There can be no patent either upon the use of compressed air as a motive power, or upon the combination of compressed air with a reheating apparatus to increase its efficacy. Patents can be granted only on new mechanical devices or combinations to utilize the energy of the compressed air. The old patents have about expired, and even if they possessed a sufficient number of years

of vitality to obstruct progress in the use of air motors, they have been superseded by new and improved devices, so that parties using compressed air motors need be under no apprehension of trouble from litigation on the part of holders of the original patents.

The only practical questions of importance are, can we calculate with certainty the amount of air that will be required at a given pressure for a given length of run, and can this air be furnished at an estimated cost that can be relied upon?

The first of these questions has been settled by the daily tests upon the Second Avenue Railroad. It has been positively determined that 300 cubic feet of free air when compressed will suffice to run a motor of the dimensions and weight there used for an average distance of one mile. If the round trip should be 12 miles, the reservoir capacity must contain 3600 cubic feet of free air plus a sufficient amount to retain an effective working pressure on the return. Consequently, if the cars are to be dispatched at intervals of one minute with a run of 12 miles, the compressor plant must have a capacity of 3600 cubic feet of free air per minute. If at intervals of 2 minutes, 1800 cubic feet; if at intervals of 4 minutes, 900 cubic feet; if at intervals of 6 minutes, 600 cubic feet; and if at intervals of 10 minutes, 360 cubic feet per minute.

As to the second question, the Norwalk Iron Works Company, the Ingersoll Rand Rock Drill Company, and several others will furnish compressor plant at fixed and reasonable prices and guarantee performanance, so that there can be no reason to apprehend disappointment from under-estimates of the engine power required, the

quantity of air compressed in a given time, or the fuel consumed and cost of compression. The extensive use of compressed air for rock-drilling, tunnelling, and other purposes, has led, since 1879, to great improvements in compressors, and removed all elements of uncertainty in regard to their operation.

A very important observation may be added, that if it should be considered desirable after a road has been some time in operation, to increase the plant and to run the cars at shorter intervals, no difficulties are presented. The power is supplied, not by a single large boiler and engine, but by a battery of boilers and several engines, and the compressor plant also consists of a number of units ; so that if the building is properly planned, additions and extensions can be made indefinitely as the increase of business may require.

Electric Motors are much better adapted to suburban service than either cable or horse power, and are coming into almost universal use where the volume of travel is neither very small nor extremely large. For a moderate business they are less expensive in installation and cheaper to operate than cable lines. They can be run, beyond the obstructed streets of populous cities, at any rate of speed that may be desired, and in suburban localities have few objectionable features except the humming noise which frightens horses.

In populous cities, narrow streets and crowded thoroughfares, the electric or trolley system is seriously objectionable. The posts and wires are not only unsightly, but they introduce a very serious impediment to the free use of fire apparatus and may thus cause wide-spread ruin. Numerous accidents from contact with live feed

wires have occurred, and contact with telephone and telegraph wires has been the supposed cause of fires and other calamities.

No electric system, except the storage battery, can furnish independent motors, and conseqnently any derangement of the central plant, or of the feed wires affects the whole line.

Electric storms sometimes disable dynamos and cause a suspension of operations upon the line.

With all these disadvantages the use of the trolley is increasing, and no doubt will continue to increase unless a better system shall be substituted and give such evidence of superior economy and efficiency as to inspire universal coufidence and supersede others of inferior merit.

In reference to the electric system of the city of Richmond, an expert writes: "The first installation there, on the Sprague System, was built without regard to cost, was the most expensive line in this country at the time, and was extensively advertised as a grand success, both practically and commercially. After the failure of this system it was bought in by other parties, and we have no information regarding the success of the latter equipment, but we presume it is equal to the average electrical road. We are well aware that great improvements have been made in the electrical equipment during the last few years, yet nevertheless there are contingencies and unlooked-for expenses which make it impossible to estimate with any certainty on the cost of operation and maintenance. The wonderful variation in figures submitted by managers of such systems attests this fact. We are in correspondence with managers of many elec-

tric roads who appear quite as anxious to-day for an independent motor as the managers of horse systems."

It is said that sleet on the feed wire and ice on the rails sometimes break the electric circuit and give trouble.

The cable system is adapted only to metropolitan lines with a very heavy business, and such lines only can prove remunerative under this system. More power is required for the movement of the cable than for the propulsion of the cars. This power must be sufficient for the work at the hours of maximum demands, and when not fully utilized at other times must result in waste. The cable must move even if there is but a single car upon the line, and to economize power at night, cable companies sometimes resort to horse-power.

The cable system is liable to derangement and blockades from various causes, of which the experience of Philadelphia during the past winter has afforded almost daily illustrations. The central machinery may be damaged, the rope may break, strands may become loose and entangle the grip so that it cannot be detached, and serious collisions and damages have resulted from this cause.

Water running into the slot, forming ice about the cable and sheaves, adds to the difficulties of winter operation.

Independent motors that consume just the amount of power required for the work to be done and no more, certainly possess great advantages over any cable system, even at the same cost for plant.

To complete the examination of motors, so far as they are known to have been used or proposed, a brief de-

scription will be given of a motor that the writer was requested to examine and give an opinion upon in 1879.

The apparatus consisted of two cylinders, each about 20 inches in diameter and 3 feet long, placed in line about 4 feet apart, and between the two a piston rod was moving slowly back and forth, making about 7 strokes per minute. The inventor and a number of capitalists who had advanced money for development were present.

Around the apartment were about 20 vertical cylinders, probably 10 feet high and 30 inches in diameter, connected by pipes so as to form a compressed-air reservoir of considerable capacity. On one of these cylinders was a steam gauge indicating 250 pounds pressure, and at one end of the row a small one-horse Baxter engine which could be set in motion by the admission of air, and which communicated rotation to a small dynamo which operated an electric light.

The inventor explained that one of the cylinders was a water engine in which motion was communicated to a piston by admitting water alternately at each end, and when the stroke was completed allowing it to escape into a waste pipe.

The use of the second cylinder the inventor refused to explain, declaring that it was his secret, but the effect was, he said, plainly visible. Here were all these reservoirs filled with air under a pressure at that time of 250 pounds to the square inch, running an electric light engine, and, he added, "Bring up one of your air motors, and I will charge it with air in one minute."

This was a very transparent fraud. The secret cylinder, no doubt, included a smaller one in which a piston

compressed air by direct action and with an enormous waste of power. The air compressed in this manner to 300 pounds per square inch would not in expanding furnish more than one-twentieth of the power expended in compression. The time required to fill the reservoir to 300 pounds of pressure would have been 36 hours, and the quantity of water expended would have been, under an assumed effective pressure of 30 pounds, 1,498,000 gallons. The time required to pump enough air to charge one motor car would have been 47 minutes.

Of course this motor was a fraud pure and simple, but quite a number of Wall Street capitalists were victimized. One gentleman said that he had advanced to the development fund ten thousand dollars; nothing has since been heard from it.

The Keely Motor has not recently exhibited any of the usual periodical spasmodic signs of vitality. That it is possible to get something out of nothing *financially* is unquestionably true, and Wall Street furnishes daily illustrations of the fact, but the laws of nature are immutable and cannot be varied. Kinetic energy cannot be transmitted without loss, and no force can be practically utilized that has not required an expenditure of a greater force in its production. The universal source of power is heat. Steam is merely an agent for transmission of force from coal to work. Cable, electric, and other systems of mechanical propulsion of cars derive their power from combustion of fuel. Water powers owe their origin to the vaporization by the heat of the sun and subsequent condensation, and even animal power is maintained by a slow combustion in the

lungs resulting in the same gaseous products that are evolved in more rapid combustion in a grate.

To claim the production of a vibrating, or any other power without the expenditure of at least an equal amount of energy in some other form, would be in opposition to natural laws, and such claimants are either ignorant and self-deceived, or they are impostors seeking to deceive others. There can be no mechanical effect without an adequate cause, and perpetual motion and Keely motors are possible only to that Being who created the world from nothing and established the laws that govern the universe.

APPENDIX.

Judson Low-pressure Air Storage System.—This is a system to which the attention of the writer has recently been directed. Its claims, as set forth in a pamphlet issued by the Judson Pneumatic Street Railway Company, are almost identical with those of the high-pressure system already fully described. The principal differences consist in the use of air at a pressure of 200 pounds to the square inch instead of 500 pounds, and arrangements for replenishing the supply in transit, at intervals of a mile, from reservoirs under the track connected with the central, or power station, by means of a 4-inch pipe. So far as public accommodation, safety, and economy are concerned, there is practically no difference between the high and low-pressure systems. Of course, high pressure requires stronger cylinders for storage than low pressure; but by increasing the thickness of metal the factor of safety can remain the same, and for a given storage capacity the high pressure will admit of reduced size of reservoirs. It is preferable, however, to make the storage capacity as large as possible without encroaching upon available space for passengers. The Judson is simply a modification of the low-pressure air system described on page 138.

From the pamphlet referred to, it appears that the

claims of the Judson Company, on which the operation of the motors depends, are identical with those of the Hardie motor of 1879, and consist of storage tanks under the seats, reducing valves to reduce pressure before admission to motor cylinders, and a reheating apparatus.

The estimate of cost of plant and of operation differs materially from the estimate on the high-pressure system on pages 101 and 102, for the reason that the conditions and data given as the basis of calculation are very dissimilar. When similar conditions are assumed, the differences disappear.

The estimate of the Judson system is made on a double-track road $7\frac{1}{2}$ miles long, with 100 cars in constant motion, running at an average speed of $8\frac{1}{2}$ miles per hour. Weight of car, 6 tons; number of passengers, 50; consumption of free air, 50 cubic feet per car-ton per mile; surplus, 20 per cent.; allowance of air per car-mile, 420 cubic feet; for the 100 cars, 42,000 cubic feet per mile, or 6000 cubic feet per minute compressed to 200 pounds; 3 sets of compressor plant of 750 horse-power each = 2250 horse-power; coal consumption, 2 pounds per horse-power, or 4500 pounds per hour; cost of compressor plant, $90,000; time of running, 20 hours; cost per day, which includes only coal and service at station, $221; cost per car-mile, with interest on plant, 2 cents; daily mileage of cars, 170 miles; cost per car-mile for coal and service, $1\frac{3}{10}$ cents.

As the estimate for cost of power in the high pressure system was $4\frac{1}{10}$ cents (page 142), it might seem, from the above statement, that the low-pressure system was

superior in economy; but the statement exhibits the usual disparity of conditions, and when brought to a standard of uniformity the differences disappear.

Coal, per horse-power—Low pressure, 2 pounds; high pressure, $2\frac{1}{2}$ pounds.

Daily mileage of each car—Low pressure, 170 miles; high pressure, 96 miles.

The low-pressure estimate of cost of power, $1\frac{3}{10}$ cents, included, as stated, only the cost of coal and the service at station. The high-pressure estimate, on the contrary, included also cost of repairs of station plant and of street motors; in fact, every item connected with power. Estimating only coal and service in the high-pressure system, the cost would be 1.48 cents per car-mile for a run of 96 miles per day; and if the average run were taken, as in the low-pressure system, at 170 miles, the cost per car-mile would be reduced, and still more if 2 pounds of coal were allowed to a horse-power instead of $2\frac{1}{2}$ pounds.

It is not claimed, however, that there are any such radical differences between the high and low-pressure systems as would result in any considerable difference of expense. In this regard the two systems may be considered as practically equal. The only important question is, Which is preferable? to use a pressure of 500 pounds and run a motor 12 miles without recharging, or to use a low pressure that will require recharging every mile? the difference in cost of charging the reservoirs being, as shown on page 55, only 1 mill per car-mile.

It may be a question, also, whether heavy falls of snow, or formation of ice around or in the feed nozzles between the tracks, might not cause trouble in winter for the low pressure system; but if it should, no doubt a remedy could be found.

On the whole, therefore, the Judson system may be considered preferable to any other now used or proposed except the high pressure, which takes its charge of air for the whole run, requires no intermediate reservoirs, and no pipe for the whole length of the track for the transmission of power. It is only in case the system should be extended to long inter-urban lines that pipes and intermediate reservoirs would become necessary, and to such lines the high-pressure system would be well adapted.

Electric Steam Motor.—A very novel design for a street motor has been brought to the attention of the writer; and as an effort has been made in this volume to present a notice of every motor known to have been used or proposed, whether good, bad, or indifferent, a few lines will be devoted to this unique candidate for popular favor.

In the electric steam motor it is proposed to use all the apparatus of an ordinary locomotive to generate steam upon a motor, and then apply this steam to rotate dynamos, which, in turn, are to communicate rotation, by means of suitable gearing, to the wheels.

In forming an opinion as to the utility of such a combination, it must be remembered that the great source of mechanical energy is heat. The heat is generated by

combustion of fuel, and is transmitted and converted into work by the intervention of certain agencies and mechanical devices.

The efforts of inventors must naturally be directed, first, to the generation of the heat, which represents work, at the lowest possible cost; and, second, its transmission and conversion into work with the least possible loss.

With stationary compound engines it is possible to secure a horse-power with 2 pounds of coal, and to run an air motor 1 mile at a cost of 7 mills for fuel.

In a small steam motor the consumption of coal is not less than 6 pounds per horse-power, and the cost per mile run cannot be less than $2\frac{8}{10}$ cents. But this is not all. The electric steam motor does not transmit the power directly to the propelling machinery, but to intermediate apparatus in the form of dynamos, which, by a system of gearing, finally transmit the power generated in the boiler to the axles of the motor.

No machinery or agency that the brain of man ever has invented or can invent will transmit energy to any distance, great or small, without loss; and, in general, the greater the number of intermediate agencies, the greater the loss.

It is not possible to transmit power from the cylinders of a locomotive through a dynamo, or other apparatus, without greater loss than would be sustained by the direct application of the power to propulsion. The only instance of the increase of power in transit is in the reheating of compressed air before admission to the motor cylinders; but as heat is the equivalent of work,

this fact does not invalidate the rule. The heat supplied is the equivalent of added energy for work.

It does not seem possible, therefore, that any economy can be secured by the proposed electric steam system; while the weight, the cost of plant and of repairs, and especially the cost of fuel, must be largely increased.

INDEX.

CATALOGUE
OF
Practical and Scientific Books
PUBLISHED BY
HENRY CAREY BAIRD & CO.

INDUSTRIAL PUBLISHERS, BOOKSELLERS AND IMPORTERS.

810 Walnut Street, Philadelphia.

☞ Any of the Books comprised in this Catalogue will be sent by mail, free of postage, to any address in the world, at the publication prices.

☞ A Descriptive Catalogue, 84 pages, 8vo., will be sent free and free of postage, to any one in any part of the world, who will furnish his address.

☞ Where not otherwise stated, all of the Books in this Catalogue are bound in muslin.

AMATEUR MECHANICS' WORKSHOP:
A treatise containing plain and concise directions for the manipulation of Wood and Metals, including Casting, Forging, Brazing, Soldering and Carpentry. By the author of the "Lathe and Its Uses." Seventh edition. Illustrated. 8vo. $2.50

ANDRES.—A Practical Treatise on the Fabrication of Volatile and Fat Varnishes, Lacquers, Siccatives and Sealing Waxes.
From the German of ERWIN ANDRES, Manufacturer of Varnishes and Lacquers. With additions on the Manufacture and Application of Varnishes, Stains for Wood, Horn, Ivory, Bone and Leather. From the German of DR. EMIL WINCKLER and LOUIS E. ANDES. The whole translated and edited by WILLIAM T. BRANNT. With 11 illustrations. 12mo. $2.50

ARLOT.—A Complete Guide for Coach Painters:
Translated from the French of M. ARLOT, Coach Painter, for eleven years Foreman of Painting to M. Eherler, Coach Maker, Paris. By A. A. FESQUET, Chemist and Engineer. To which is added an Appendix, containing Information respecting the Materials and the Practice of Coach and Car Painting and Varnishing in the United States and Great Britain. 12mo. $1.25

ARMENGAUD, AMOROUX, AND JOHNSON.—The Practical Draughtsman's Book of Industrial Design, and Machinist's and Engineer's Drawing Companion:

Forming a Complete Course of Mechanical Engineering and Architectural Drawing. From the French of M. Armengaud the elder, Prof. of Design in the Conservatoire of Arts and Industry, Paris, and MM. Armengaud the younger, and Amoroux, Civil Engineers. Rewritten and arranged with additional matter and plates, selections from and examples of the most useful and generally employed mechanism of the day. By WILLIAM JOHNSON, Assoc. Inst. C. E. Illustrated by fifty folio steel plates, and fifty wood-cuts. A new edition, 4to., half morocco $10.00

ARMSTRONG.—The Construction and Management of Steam Boilers:

By R. ARMSTRONG, C. E. With an Appendix by ROBERT MALLET, C. E., F. R. S. Seventh Edition. Illustrated. 1 vol. 12mo. 75

ARROWSMITH.—Paper-Hanger's Companion:

A Treatise in which the Practical Operations of the Trade are Systematically laid down: with Copious Directions Preparatory to Papering; Preventives against the Effect of Damp on Walls; the various Cements and Pastes Adapted to the Several Purposes of the Trade; Observations and Directions for the Panelling and Ornamenting of Rooms, etc. By JAMES ARROWSMITH. 12mo., cloth $1.25

ASHTON.—The Theory and Practice of the Art of Designing Fancy Cotton and Woollen Cloths from Sample:

Giving full instructions for reducing drafts, as well as the methods of spooling and making out harness for cross drafts and finding any required reed; with calculations and tables of yarn. By FREDERIC T. ASHTON, Designer, West Pittsfield, Mass. With fifty-two illustrations. One vol. folio $6.00

ASKINSON.—Perfumes and their Preparation:

A Comprehensive Treatise on Perfumery, containing Complete Directions for Making Handkerchief Perfumes, Smelling-Salts, Sachets, Fumigating Pastils; Preparations for the Care of the Skin, the Mouth, the Hair; Cosmetics, Hair Dyes, and other Toilet Articles. By G. W. ASKINSON. Translated from the German by ISIDOR FURST. Revised by CHARLES RICE. 32 Illustrations. 8vo. $3.00

BAIRD.—Miscellaneous Papers on Economic Questions. By Henry Carey Baird. (*In preparation.*)

BAIRD.—The American Cotton Spinner, and Manager's and Carder's Guide:

A Practical Treatise on Cotton Spinning; giving the Dimensions and Speed of Machinery, Draught and Twist Calculations, etc.; with notices of recent Improvements: together with Rules and Examples for making changes in the sizes and numbers of Roving and Yarn. Compiled from the papers of the late ROBERT H. BAIRD. 12mo. $1.50

BAIRD.—Standard Wages Computing Tables:
An Improvement in all former Methods of Computation, so arranged that wages for days, hours, or fractions of hours, at a specified rate per day or hour, may be ascertained at a glance. By T. SPANGLER BAIRD. Oblong folio $5.00

BAKER.—Long-Span Railway Bridges:
Comprising Investigations of the Comparative Theoretical and Practical Advantages of the various Adopted or Proposed Type Systems of Construction; with numerous Formulæ and Tables. By B. BAKER. 12mo. $1.50

BAKER.—The Mathematical Theory of the Steam-Engine:
With Rules at length, and Examples worked out for the use of Practical Men. By T. BAKER, C. E., with numerous Diagrams. Sixth Edition, Revised by Prof. J. R. YOUNG. 12mo. . 75

BARLOW.—The History and Principles of Weaving, by Hand and by Power:
Reprinted, with Considerable Additions, from "Engineering," with a chapter on Lace-making Machinery, reprinted from the Journal of the "Society of Arts." By ALFRED BARLOW. With several hundred illustrations. 8vo., 443 pages $10.00

BARR.—A Practical Treatise on the Combustion of Coal:
Including descriptions of various mechanical devices for the Economic Generation of Heat by the Combustion of Fuel, whether solid, liquid or gaseous. 8vo. $2.50

BARR.—A Practical Treatise on High Pressure Steam Boilers:
Including Results of Recent Experimental Tests of Boiler Materials, together with a Description of Approved Safety Apparatus, Steam Pumps, Injectors and Economizers in actual use. By WM. M. BARR. 204 Illustrations. 8vo. $3.00

BAUERMAN.—A Treatise on the Metallurgy of Iron:
Containing Outlines of the History of Iron Manufacture, Methods of Assay, and Analysis of Iron Ores, Processes of Manufacture of Iron and Steel, etc., etc. By H. BAUERMAN, F. G. S., Associate of the Royal School of Mines. Fifth Edition, Revised and Enlarged. Illustrated with numerous Wood Engravings from Drawings by J. B. JORDAN. 12mo. $2.00

BAYLES.—House Drainage and Water Service:
In Cities, Villages and Rural Neighborhoods. With Incidental Consideration of Certain Causes Affecting the Healthfulness of Dwellings. By JAMES C. BAYLES, Editor of "The Iron Age" and "The Metal Worker." With numerous illustrations. 8vo. cloth,

BEANS.—A Treatise on Railway Curves and Location of Railroads:
By E. W. BEANS, C. E. Illustrated. 12mo. Tucks . $1.50

BECKETT.—A Rudimentary Treatise on Clocks, and Watches and Bells:
By Sir EDMUND BECKETT, Bart., LL. D., Q. C. F. R. A. S. With numerous illustrations. Seventh Edition, Revised and Enlarged. 12mo. $2.25

BELL.—Carpentry Made Easy:

Or, The Science and Art of Framing on a New and Improved System. With Specific Instructions for Building Balloon Frames, Barn Frames, Mill Frames, Warehouses, Church Spires, etc. Comprising also a System of Bridge Building, with Bills, Estimates of Cost, and valuable Tables. Illustrated by forty-four plates, comprising nearly 200 figures. By WILLIAM E. BELL, Architect and Practical Builder. 8vo. $5.00

BEMROSE.—Fret-Cutting and Perforated Carving:

With fifty-three practical illustrations. By W. BEMROSE, JR. 1 vol. quarto $2.50

BEMROSE.—Manual of Buhl-work and Marquetry:

With Practical Instructions for Learners, and ninety colored designs. By W. BEMROSE, JR. 1 vol. quarto $3.00

BEMROSE.—Manual of Wood Carving:

With Practical Illustrations for Learners of the Art, and Original and Selected Designs. By WILLIAM BEMROSE, JR. With an Introduction by LLEWELLYN JEWITT, F. S. A., etc. With 128 illustrations, 4to. $2.50

BILLINGS.—Tobacco:

Its History, Variety, Culture, Manufacture, Commerce, and Various Modes of Use. By E. R. BILLINGS. Illustrated by nearly 200 engravings. 8vo. $3.00

BIRD.—The American Practical Dyers' Companion:

Comprising a Description of the Principal Dye-Stuffs and Chemicals used in Dyeing, their Natures and Uses; Mordants, and How Made; with the best American, English, French and German processes for Bleaching and Dyeing Silk, Wool, Cotton, Linen, Flannel, Felt, Dress Goods, Mixed and Hosiery Yarns, Feathers, Grass, Felt, Fur, Wool, and Straw Hats, Jute Yarn, Vegetable Ivory, Mats, Skins, Furs, Leather, etc., etc. By Wood, Aniline, and other Processes, together with Remarks on Finishing Agents, and Instructions in the Finishing of Fabrics, Substitutes for Indigo, Water-Proofing of Materials, Tests and Purification of Water, Manufacture of Aniline and other New Dye Wares, Harmonizing Colors, etc., etc.; embracing in all over 800 Receipts for Colors and Shades, *accompanied by 170 Dyed Samples of Raw Materials and Fabrics.* By F. J. BIRD, Practical Dyer, Author of "The Dyers' Hand-Book." 8vo. $10.00

BLINN.—A Practical Workshop Companion for Tin, Sheet-Iron, and Copper-plate Workers:

Containing Rules for describing various kinds of Patterns used by Tin, Sheet-Iron and Copper-plate Workers; Practical Geometry; Mensuration of Surfaces and Solids; Tables of the Weights of Metals, Lead-pipe, etc.; Tables of Areas and Circumferences of Circles; Japan, Varnishes, Lackers, Cements, Compositions, etc., etc. By LEROY J. BLINN, Master Mechanic. With One Hundred and Seventy Illustrations. 12mo. $2.50

BOOTH.—Marble Worker's Manual:
Containing Practical Information respecting Marbles in general, their Cutting, Working and Polishing; Veneering of Marble; Mosaics; Composition and Use of Artificial Marble, Stuccos, Cements, Receipts, Secrets, etc., etc. Translated from the French by M. L. BOOTH. With an Appendix concerning American Marbles. 12mo., cloth $1.50

BOOTH and MORFIT.—The Encyclopædia of Chemistry, Practical and Theoretical:
Embracing its application to the Arts, Metallurgy, Mineralogy, Geology, Medicine and Pharmacy. By JAMES C. BOOTH, Melter and Refiner in the United States Mint, Professor of Applied Chemistry in the Franklin Institute, etc., assisted by CAMPBELL MORFIT, author of "Chemical Manipulations," etc. Seventh Edition. Complete in one volume, royal 8vo., 978 pages, with numerous wood-cuts and other illustrations $3.50

BRAMWELL.—The Wool Carder's Vade-Mecum:
A Complete Manual of the Art of Carding Textile Fabrics. By W. C. BRAMWELL. Third Edition, revised and enlarged. Illustrated. Pp. 400. 12mo. $2.50

BRANNT.—A Practical Treatise on Animal and Vegetable Fats and Oils:
Comprising both Fixed and Volatile Oils, their Physical and Chemical Properties and Uses, the Manner of Extracting and Refining them, and Practical Rules for Testing them; as well as the Manufacture of Artificial Butter, Lubricants, including Mineral Lubricating Oils, etc., and on Ozokerite. Edited chiefly from the German of DRS. KARL SCHAEDLER, G. W. ASKINSON, and RICHARD BRUNNER, with Additions and Lists of American Patents relating to the Extraction, Rendering, Refining, Decomposing, and Bleaching of Fats and Oils. By WILLIAM T. BRANNT. Illustrated by 244 engravings. 739 pages. 8vo. $7.50

BRANNT.—A Practical Treatise on the Manufacture of Soap and Candles:
Based upon the most Recent Experiences in the Practice and Science; comprising the Chemistry, Raw Materials, Machinery, and Utensils and Various Processes of Manufacture, including a great variety of formulas. Edited chiefly from the German of Dr. C. Deite, A. Engelhardt, Dr. C. Schaedler and others; with additions and lists of American Patents relating to these subjects. By WM. T. BRANNT. Illustrated by 163 engravings. 677 pages. 8vo. . . $7.50

BRANNT.—A Practical Treatise on the Raw Materials and the Distillation and Rectification of Alcohol, and the Preparation of Alcoholic Liquors, Liqueurs, Cordials, Bitters, etc.:
Edited chiefly from the German of Dr. K. Stammer, Dr. F. Elsner, and E. Schubert. By WM. T. BRANNT. Illustrated by thirty-one engravings. 12mo. $2.50

BRANNT—WAHL.—The Techno-Chemical Receipt Book:
Containing several thousand Receipts covering the latest, most important, and most useful discoveries in Chemical Technology, and their Practical Application in the Arts and the Industries. Edited chiefly from the German of Drs. Winckler, Elsner, Heintze, Mierzinski, Jacobsen, Koller, and Heinzerling, with additions by WM. T. BRANNT and WM. H. WAHL, PH. D. Illustrated by 78 engravings. 12mo. 495 pages $2.00

BROWN.—Five Hundred and Seven Mechanical Movements:
Embracing all those which are most important in Dynamics, Hydraulics, Hydrostatics, Pneumatics, Steam-Engines, Mill and other Gearing, Presses, Horology and Miscellaneous Machinery; and including many movements never before published, and several of which have only recently come into use. By HENRY T. BROWN. 12mo. $1:00

BUCKMASTER.—The Elements of Mechanical Physics:
By J. C. BUCKMASTER. Illustrated with numerous engravings. 12mo. $1.00

BULLOCK.—The American Cottage Builder:
A Series of Designs, Plans and Specifications, from $200 to $20,000, for Homes for the People; together with Warming, Ventilation, Drainage, Painting and Landscape Gardening. By JOHN BULLOCK, Architect and Editor of "The Rudiments of Architecture and Building," etc., etc. Illustrated by 75 engravings. 8vo. $3.50

BULLOCK.—The Rudiments of Architecture and Building:
For the use of Architects, Builders, Draughtsmen, Machinists, Engineers and Mechanics. Edited by JOHN BULLOCK, author of "The American Cottage Builder." Illustrated by 250 Engravings. 8vo. $3.50

BURGH.—Practical Rules for the Proportions of Modern Engines and Boilers for Land and Marine Purposes.
By N. P. BURGH, Engineer. 12mo. $1.50

BYLES.—Sophisms of Free Trade and Popular Political Economy Examined.
By a BARRISTER (SIR JOHN BARNARD BYLES, Judge of Common Pleas). From the Ninth English Edition, as published by the Manchester Reciprocity Association. 12mo. $1.25

BOWMAN.—The Structure of the Wool Fibre in its Relation to the Use of Wool for Technical Purposes:
Being the substance, with additions, of Five Lectures, delivered at the request of the Council, to the members of the Bradford Technical College, and the Society of Dyers and Colorists. By F. H. BOWMAN, D. Sc., F. R. S. E., F. L. S. Illustrated by 32 engravings. 8vo. $6.50

BYRNE.—Hand-Book for the Artisan, Mechanic, and Engineer:
Comprising the Grinding and Sharpening of Cutting Tools, Abrasive Processes, Lapidary Work, Gem and Glass Engraving, Varnishing and Lackering, Apparatus, Materials and Processes for Grinding and

Polishing, etc. By OLIVER BYRNE. Illustrated by 185 wood engravings. 8vo. $5.00

BYRNE.—Pocket-Book for Railroad and Civil Engineers:
Containing New, Exact and Concise Methods for Laying out Railroad Curves, Switches, Frog Angles and Crossings; the Staking out of work; Levelling; the Calculation of Cuttings; Embankments; Earthwork, etc. By OLIVER BYRNE. 18mo., full bound, pocket-book form $1.75

BYRNE.—The Practical Metal-Worker's Assistant:
Comprising Metallurgic Chemistry; the Arts of Working all Metals and Alloys; Forging of Iron and Steel; Hardening and Tempering; Melting and Mixing; Casting and Founding; Works in Sheet Metal; the Processes Dependent on the Ductility of the Metals; Soldering; and the most Improved Processes and Tools employed by Metal-Workers. With the Application of the Art of Electro-Metallurgy to Manufacturing Processes; collected from Original Sources, and from the works of Holtzapffel, Bergeron, Leupold, Plumier, Napier, Scoffern, Clay, Fairbairn and others. By OLIVER BYRNE. A new, revised and improved edition, to which is added an Appendix, containing The Manufacture of Russian Sheet-Iron. By JOHN PERCY, M. D., F. R. S. The Manufacture of Malleable Iron Castings, and Improvements in Bessemer Steel. By A. A. FESQUET, Chemist and Engineer. With over Six Hundred Engravings, Illustrating every Branch of the Subject. 8vo. $5.00

BYRNE.—The Practical Model Calculator:
For the Engineer, Mechanic, Manufacturer of Engine Work, Naval Architect, Miner and Millwright. By OLIVER BYRNE. 8vo., nearly 600 pages $4.50

CABINET MAKER'S ALBUM OF FURNITURE:
Comprising a Collection of Designs for various Styles of Furniture. Illustrated by Forty-eight Large and Beautifully Engraved Plates. Oblong, 8vo. $2.00

CALLINGHAM.—Sign Writing and Glass Embossing:
A Complete Practical Illustrated Manual of the Art. By JAMES CALLINGHAM. 12mo. $1.50

CAMPIN.—A Practical Treatise on Mechanical Engineering:
Comprising Metallurgy, Moulding, Casting, Forging, Tools, Workshop Machinery, Mechanical Manipulation, Manufacture of Steam-Engines, etc. With an Appendix on the Analysis of Iron and Iron Ores. By FRANCIS CAMPIN, C. E. To which are added, Observations on the Construction of Steam Boilers, and Remarks upon Furnaces used for Smoke Prevention; with a Chapter on Explosions. By R. ARMSTRONG, C. E., and JOHN BOURNE. Rules for Calculating the Change Wheels for Screws on a Turning Lathe, and for a Wheel-cutting Machine. By J. LA NICCA. Management of Steel, Including Forging, Hardening, Tempering, Annealing, Shrinking and Expansion; and the Case-hardening of Iron. By G. EDE. 8vo. Illustrated with twenty-nine plates and 100 wood engravings $5.00

CAREY.—A Memoir of Henry C. Carey.
By DR. WM. ELDER. With a portrait. 8vo., cloth . . 75

CAREY.—The Works of Henry C. Carey:
Harmony of Interests: Agricultural, Manufacturing and Commercial. 8vo. $1.25
Manual of Social Science. Condensed from Carey's "Principles of Social Science." By KATE MCKEAN. 1 vol. 12mo. . $2.25
Miscellaneous Works. With a Portrait. 2 vols. 8vo. $10.00
Past, Present and Future. 8vo. $2.50
Principles of Social Science. 3 volumes, 8vo. . . $7.50
The Slave-Trade, Domestic and Foreign; Why it Exists, and How it may be Extinguished (1853). 8vo. . . . $2.00
The Unity of Law: As Exhibited in the Relations of Physical, Social, Mental and Moral Science (1872). 8vo. . . $2.50

CLARK.—Tramways, their Construction and Working:
Embracing a Comprehensive History of the System. With an exhaustive analysis of the various modes of traction, including horse-power, steam, heated water and compressed air; a description of the varieties of Rolling stock, and ample details of cost and working expenses. By D. KINNEAR CLARK. Illustrated by over 200 wood engravings, and thirteen folding plates. 2 vols. 8vo. . $12.50

COLBURN.—The Locomotive Engine:
Including a Description of its Structure, Rules for Estimating its Capabilities, and Practical Observations on its Construction and Management. By ZERAH COLBURN. Illustrated. 12mo. . $1.00

COLLENS.—The Eden of Labor; or, the Christian Utopia.
By T. WHARTON COLLENS, author of "Humanics," "The History of Charity," etc. 12mo. Paper cover, $1.00; Cloth . $1.25

COOLEY.—A Complete Practical Treatise on Perfumery:
Being a Hand-book of Perfumes, Cosmetics and other Toilet Articles. With a Comprehensive Collection of Formulæ. By ARNOLD J. COOLEY. 12mo. $1.50

COOPER.—A Treatise on the use of Belting for the Transmission of Power.
With numerous illustrations of approved and actual methods of arranging Main Driving and Quarter Twist Belts, and of Belt Fastenings. Examples and Rules in great number for exhibiting and calculating the size and driving power of Belts. Plain, Particular and Practical Directions for the Treatment, Care and Management of Belts. Descriptions of many varieties of Beltings, together with chapters on the Transmission of Power by Ropes; by Iron and Wood Frictional Gearing; on the Strength of Belting Leather; and on the Experimental Investigations of Morin, Briggs, and others. By JOHN H. COOPER, M. E. 8vo. $3.50

CRAIK.—The Practical American Millwright and Miller.
By DAVID CRAIK, Millwright. Illustrated by numerous wood engravings and two folding plates. 8vo. $3.50

CREW.—A Practical Treatise on Petroleum:
Comprising its Origin, Geology, Geographical Distribution, History, Chemistry, Mining, Technology, Uses and Transportation. Together with a Description of Gas Wells, the Application of Gas as Fuel, etc. By BENJAMIN J. CREW. With an Appendix on the Product and Exhaustion of the Oil Regions, and the Geology of Natural Gas in Pennsylvania and New York. By CHARLES A. ASHBURNER, M. S., Geologist in Charge Pennsylvania Survey, Philadelphia. Illustrated by 70 engravings. 8vo. 508 pages $5.00

CROSS.—The Cotton Yarn Spinner:
Showing how the Preparation should be arranged for Different Counts of Yarns by a System more uniform than has hitherto been practiced; by having a Standard Schedule from which we make all our Changes. By RICHARD CROSS. 122 pp. 12mo. . 75

CRISTIANI.—A Technical Treatise on Soap and Candles:
With a Glance at the Industry of Fats and Oils. By R. S. CRISTIANI, Chemist. Author of "Perfumery and Kindred Arts." Illustrated by 176 engravings. 581 pages, 8vo. . . . $15.00

CRISTIANI.—Perfumery and Kindred Arts:
A Comprehensive Treatise on Perfumery, containing a History of Perfumes from the remotest ages to the present time. A complete detailed description of the various Materials and Apparatus used in the Perfumer's Art, with thorough Practical Instruction and careful Formulæ, and advice for the fabrication of all known preparations of the day, including Essences, Tinctures, Extracts, Spirits, Waters, Vinegars, Pomades, Powders, Paints, Oils, Emulsions, Cosmetics, Infusions, Pastilles, Tooth Powders and Washes, Cachous, Hair Dyes, Sachets, Essential Oils, Flavoring Extracts, etc.; and full details for making and manipulating Fancy Toilet Soaps, Shaving Creams, etc., by new and improved methods. With an Appendix giving hints and advice for making and fermenting Domestic Wines, Cordials, Liquors, Candies, Jellies, Syrups, Colors, etc., and for Perfuming and Flavoring Segars, Snuff and Tobacco, and Miscellaneous Receipts for various useful Analogous Articles. By R. S. CRISTIANI, Consulting Chemist and Perfumer, Philadelphia. 8vo. . . $10.00

DAVIDSON.—A Practical Manual of House Painting, Graining, Marbling, and Sign-Writing:
Containing full information on the processes of House Painting in Oil and Distemper, the Formation of Letters and Practice of Sign-Writing, the Principles of Decorative Art, a Course of Elementary Drawing for House Painters, Writers, etc., and a Collection of Useful Receipts. With nine colored illustrations of Woods and Marbles, and numerous wood engravings. By ELLIS A. DAVIDSON. 12mo. $3.00

DAVIES.—A Treatise on Earthy and Other Minerals and Mining:
By D. C. DAVIES, F. G. S., Mining Engineer, etc. Illustrated by 76 Engravings. 12mo. $5.00

DAVIES.—A Treatise on Metalliferous Minerals and Mining:
By D. C. DAVIES, F. G. S., Mining Engineer, Examiner of Mines, Quarries and Collieries. Illustrated by 148 engravings of Geological Formations, Mining Operations and Machinery, drawn from the practice of all parts of the world. 2d Edition, 12mo., 450 pages $5.00

DAVIES.—A Treatise on Slate and Slate Quarrying:
Scientific, Practical and Commercial. By D. C. DAVIES, F. G. S., Mining Engineer, etc. With numerous illustrations and folding plates. 12mo. $2.00

DAVIS.—A Treatise on Steam-Boiler Incrustation and Methods for Preventing Corrosion and the Formation of Scale:
By CHARLES T. DAVIS. Illustrated by 65 engravings. 8vo. $1.50

DAVIS.—The Manufacture of Paper:
Being a Description of the various Processes for the Fabrication, Coloring and Finishing of every kind of Paper, Including the Different Raw Materials and the Methods for Determining their Values, the Tools, Machines and Practical Details connected with an intelligent and a profitable prosecution of the art, with special reference to the best American Practice. To which are added a History of Paper, complete Lists of Paper-Making Materials, List of American Machines, Tools and Processes used in treating the Raw Materials, and in Making, Coloring and Finishing Paper. By CHARLES T. DAVIS. Illustrated by 156 engravings. 608 pages, 8vo. $6.00

DAVIS.—The Manufacture of Leather:
Being a description of all of the Processes for the Tanning, Tawing, Currying, Finishing and Dyeing of every kind of Leather; including the various Raw Materials and the Methods for Determining their Values; the Tools, Machines, and all Details of Importance connected with an Intelligent and Profitable Prosecution of the Art, with Special Reference to the Best American Practice. To which are added Complete Lists of all American Patents for Materials, Processes, Tools, and Machines for Tanning, Currying, etc. By CHARLES THOMAS DAVIS. Illustrated by 302 engravings and 12 Samples of Dyed Leathers. One vol., 8vo., 824 pages . . . $10.00

DAWIDOWSKY—BRANNT.—A Practical Treatise on the Raw Materials and Fabrication of Glue, Gelatine, Gelatine Veneers and Foils, Isinglass, Cements, Pastes, Mucilages, etc.:
Based upon Actual Experience. By F. DAWIDOWSKY, Technical Chemist. Translated from the German, with extensive additions, including a description of the most Recent American Processes, by WILLIAM T. BRANNT, Graduate of the Royal Agricultural College of Eldena, Prussia. 35 Engravings. 12mo. $2.50

DE GRAFF.—The Geometrical Stair-Builders' Guide:
Being a Plain Practical System of Hand-Railing, embracing all its necessary Details, and Geometrically Illustrated by twenty-two Steel Engravings; together with the use of the most approved principles of Practical Geometry. By SIMON DE GRAFF, Architect. 4to. $2.50

DE KONINCK—DIETZ.—A Practical Manual of Chemical Analysis and Assaying:

As applied to the Manufacture of Iron from its Ores, and to Cast Iron, Wrought Iron, and Steel, as found in Commerce. By L. L. DE KONINCK, Dr. Sc., and E. DIETZ, Engineer. Edited with Notes, by ROBERT MALLET, F. R. S., F. S. G., M. I. C. E., etc. American Edition, Edited with Notes and an Appendix on Iron Ores, by A. A. FESQUET, Chemist and Engineer. 12mo. $1.50

DUNCAN.—Practical Surveyor's Guide:

Containing the necessary information to make any person of common capacity, a finished land surveyor without the aid of a teacher By ANDREW DUNCAN. Revised. 72 engravings, 214 pp. 12mo. $1.50

DUPLAIS.—A Treatise on the Manufacture and Distillation of Alcoholic Liquors:

Comprising Accurate and Complete Details in Regard to Alcohol from Wine, Molasses, Beets, Grain, Rice, Potatoes, Sorghum, Asphodel, Fruits, etc.; with the Distillation and Rectification of Brandy, Whiskey, Rum, Gin, Swiss Absinthe, etc., the Preparation of Aromatic Waters, Volatile Oils or Essences, Sugars, Syrups, Aromatic Tinctures, Liqueurs, Cordial Wines, Effervescing Wines, etc., the Ageing of Brandy and the improvement of Spirits, with Copious Directions and Tables for Testing and Reducing Spirituous Liquors, etc., etc. Translated and Edited from the French of MM. DUPLAIS, Ainè et Jeune. By M. MCKENNIE, M. D. To which are added the United States Internal Revenue Regulations for the Assessment and Collection of Taxes on Distilled Spirits. Illustrated by fourteen folding plates and several wood engravings. 743 pp. 8vo. $10 00

DUSSAUCE.—Practical Treatise on the Fabrication of Matches, Gun Cotton, and Fulminating Powder.

By Professor H. DUSSAUCE. 12mo. $3 00

DYER AND COLOR-MAKER'S COMPANION:

Containing upwards of two hundred Receipts for making Colors, on the most approved principles, for all the various styles and fabrics now in existence; with the Scouring Process, and plain Directions for Preparing, Washing-off, and Finishing the Goods. 12mo. $1 25

EDWARDS.—A Catechism of the Marine Steam-Engine,

For the use of Engineers, Firemen, and Mechanics. A Practical Work for Practical Men. By EMORY EDWARDS, Mechanical Engineer. Illustrated by sixty-three Engravings, including examples of the most modern Engines. Third edition, thoroughly revised, with much additional matter. 12mo. 414 pages $2 00

EDWARDS.—Modern American Locomotive Engines,

Their Design, Construction and Management. By EMORY EDWARDS. Illustrated 12mo. $2.00

EDWARDS.—The American Steam Engineer:

Theoretical and Practical, with examples of the latest and most approved American practice in the design and construction of Steam Engines and Boilers. For the use of engineers, machinists, boiler-makers, and engineering students. By EMORY EDWARDS. Fully illustrated, 419 pages. 12mo. $2.50

EDWARDS.—Modern American Marine Engines, Boilers, and Screw Propellers,

Their Design and Construction. Showing the Present Practice of the most Eminent Engineers and Marine Engine Builders in the United States. Illustrated by 30 large and elaborate plates. 4to. $5.00

EDWARDS.—The Practical Steam Engineer's Guide

In the Design, Construction, and Management of American Stationary, Portable, and Steam Fire-Engines, Steam Pumps, Boilers, Injectors, Governors, Indicators, Pistons and Rings, Safety Valves and Steam Gauges. For the use of Engineers, Firemen, and Steam Users. By EMORY EDWARDS. Illustrated by 119 engravings. 420 pages. 12mo. $2 50

EISSLER.—The Metallurgy of Gold:

A Practical Treatise on the Metallurgical Treatment of Gold-Bearing Ores, including the Processes of Concentration and Chlorination, and the Assaying, Melting, and Refining of Gold. By M. EISSLER. With 132 Illustrations. 12mo. $3.50

EISSLER.—The Metallurgy of Silver:

A Practical Treatise on the Amalgamation, Roasting, and Lixiviation of Silver Ores, including the Assaying, Melting, and Refining of Silver Bullion. By M. EISSLER. 124 Illustrations. 336 pp. 12mo. $4.25

ELDER.—Conversations on the Principal Subjects of Political Economy.

By DR. WILLIAM ELDER. 8vo. $2.50

ELDER.—Questions of the Day,

Economic and Social. By DR. WILLIAM ELDER. 8vo. . $3.00

ERNI.—Mineralogy Simplified.

Easy Methods of Determining and Classifying Minerals, including Ores, by means of the Blowpipe, and by Humid Chemical Analysis, based on Professor von Kobell's Tables for the Determination of Minerals, with an Introduction to Modern Chemistry. By HENRY ERNI, A.M., M.D., Professor of Chemistry. Second Edition, rewritten, enlarged and improved. 12mo. $3.00

FAIRBAIRN.—The Principles of Mechanism and Machinery of Transmission:

Comprising the Principles of Mechanism, Wheels, and Pulleys, Strength and Proportions of Shafts, Coupling of Shafts, and Engaging and Disengaging Gear. By SIR WILLIAM FAIRBAIRN, Bart. C. E. Beautifully illustrated by over 150 wood-cuts. In one volume, 12mo $2.50

FLEMING.—Narrow Gauge Railways in America.

A Sketch of their Rise, Progress, and Success. Valuable Statistics as to Grades, Curves, Weight of Rail, Locomotives, Cars, etc. By HOWARD FLEMING. Illustrated, 8vo. $1 00

FORSYTH.—Book of Designs for Headstones, Mural, and other Monuments:

Containing 78 Designs. By JAMES FORSYTH. With an Introduction by CHARLES BOUTELL, M. A. 4 to., cloth . . . $5 00

FRANKEL—HUTTER.—A Practical Treatise on the Manufacture of Starch, Glucose, Starch-Sugar, and Dextrine:
Based on the German of LADISLAUS VON WAGNER, Professor in the Royal Technical High School, Buda-Pest, Hungary, and other authorities. By JULIUS FRANKEL, Graduate of the Polytechnic School of Hanover. Edited by ROBERT HUTTER, Chemist, Practical Manufacturer of Starch-Sugar. Illustrated by 58 engravings, covering every branch of the subject, including examples of the most Recent and Best American Machinery. 8vo., 344 pp. . $3.50

GARDNER.—The Painter's Encyclopædia:
Containing Definitions of all Important Words in the Art of Plain and Artistic Painting, with Details of Practice in Coach, Carriage, Railway Car, House, Sign, and Ornamental Painting, including Graining, Marbling, Staining, Varnishing, Polishing, Lettering, Stenciling, Gilding, Bronzing, etc. By FRANKLIN B. GARDNER. 158 Illustrations. 12mo. 427 pp. $2.00

GARDNER.—Everybody's Paint Book:
A Complete Guide to the Art of Outdoor and Indoor Painting, Designed for the Special Use of those who wish to do their own work, and consisting of Practical Lessons in Plain Painting, Varnishing, Polishing, Staining, Paper Hanging, Kalsomining, etc., as well as Directions for Renovating Furniture, and Hints on Artistic Work for Home Decoration. 38 Illustrations. 12mo., 183 pp. . $1.00

GEE.—The Goldsmith's Handbook:
Containing full instructions for the Alloying and Working of Gold, including the Art of Alloying, Melting, Reducing, Coloring, Collecting, and Refining; the Processes of Manipulation, Recovery of Waste; Chemical and Physical Properties of Gold; with a New System of Mixing its Alloys; Solders, Enamels, and other Useful Rules and Recipes. By GEORGE E. GEE. 12mo. . . $1.75

GEE.—The Silversmith's Handbook:
Containing full instructions for the Alloying and Working of Silver, including the different modes of Refining and Melting the Metal; its Solders; the Preparation of Imitation Alloys; Methods of Manipulation; Prevention of Waste; Instructions for Improving and Finishing the Surface of the Work; together with other Useful Information and Memoranda. By GEORGE E. GEE. Illustrated. 12mo. $1.75

GOTHIC ALBUM FOR CABINET-MAKERS:
Designs for Gothic Furniture. Twenty-three plates. Oblong $2.00

GRANT.—A Handbook on the Teeth of Gears:
Their Curves, Properties, and Practical Construction. By GEORGE B. GRANT. Illustrated. Third Edition, enlarged. 8vo. $1.00

GREENWOOD.—Steel and Iron:
Comprising the Practice and Theory of the Several Methods Pursued in their Manufacture, and of their Treatment in the Rolling-Mills, the Forge, and the Foundry. By WILLIAM HENRY GREENWOOD, F. C. S. With 97 Diagrams, 536 pages. 12mo. $2.00

GREGORY.—Mathematics for Practical Men:
Adapted to the Pursuits of Surveyors, Architects, Mechanics, and Civil Engineers. By OLINTHUS GREGORY. 8vo., plates $3.00

GRIMSHAW.—Saws:
The History, Development, Action, Classification, and Comparison of Saws of all kinds. *With Copious Appendices.* Giving the details of Manufacture, Filing, Setting, Gumming, etc. Care and Use of Saws; Tables of Gauges; Capacities of Saw-Mills; List of Saw-Patents, and other valuable information. By ROBERT GRIMSHAW. Second and greatly enlarged edition, *with Supplement,* and 354 Illustrations. Quarto $6.00

GRISWOLD.—Railroad Engineer's Pocket Companion for the Field:
Comprising Rules for Calculating Deflection Distances and Angles, Tangential Distances and Angles, and all Necessary Tables for Engineers; also the Art of Levelling from Preliminary Survey to the Construction of Railroads, intended Expressly for the Young Engineer, together with Numerous Valuable Rules and Examples. By W. GRISWOLD. 12mo., tucks $1.75

GRUNER.—Studies of Blast Furnace Phenomena:
By M. L. GRUNER, President of the General Council of Mines of France, and lately Professor of Metallurgy at the Ecole des Mines. Translated, with the author's sanction, with an Appendix, by L. D. B. GORDON, F. R. S. E., F. G. S. 8vo. $2.50

Hand-Book of Useful Tables for the Lumberman, Farmer and Mechanic:
Containing Accurate Tables of Logs Reduced to Inch Board Measure, Plank, Scantling and Timber Measure; Wages and Rent, by Week or Month; Capacity of Granaries, Bins and Cisterns; Land Measure, Interest Tables, with Directions for Finding the Interest on any sum at 4, 5, 6, 7 and 8 per cent., and many other Useful Tables. 32 mo., boards. 186 pages 25

HASERICK.—The Secrets of the Art of Dyeing Wool, Cotton, and Linen,
Including Bleaching and Coloring Wool and Cotton Hosiery and Random Yarns. A Treatise based on Economy and Practice. By E. C. HASERICK. *Illustrated by 323 Dyed Patterns of the Yarns or Fabrics.* 8vo. $7.50

HATS AND FELTING:
A Practical Treatise on their Manufacture. By a Practical Hatter. Illustrated by Drawings of Machinery, etc. 8vo. . . . $1.25

HOFFER.—A Practical Treatise on Caoutchouc and Gutta Percha,
Comprising the Properties of the Raw Materials, and the manner of Mixing and Working them; with the Fabrication of Vulcanized and Hard Rubbers, Caoutchouc and Gutta Percha Compositions, Waterproof Substances, Elastic Tissues, the Utilization of Waste, etc., etc. From the German of RAIMUND HOFFER. By W. T. BRANNT. Illustrated 12mo. $2.50

HAUPT—RHAWN.—A Move for Better Roads:
Essays on Road-making and Maintenance and Road Laws, for which Prizes or Honorable Mention were Awarded through the University of Pennsylvania by a Committee of Citizens of Philadelphia, with a Synopsis of other Contributions and a Review by the Secretary, LEWIS M. HAUPT, A. M., C. E.; also an Introduction by WILLIAM H. RHAWN, Chairman of the Committee. 319 pages. 8vo. $2.00

HUGHES.—American Miller and Millwright's Assistant:
By WILLIAM CARTER HUGHES. 12mo. $1.50

HULME.—Worked Examination Questions in Plane Geometrical Drawing:
For the Use of Candidates for the Royal Military Academy, Woolwich; the Royal Military College, Sandhurst; the Indian Civil Engineering College, Cooper's Hill; Indian Public Works and Telegraph Departments; Royal Marine Light Infantry; the Oxford and Cambridge Local Examinations, etc. By F. EDWARD HULME, F. L. S., F. S. A., Art-Master Marlborough College. Illustrated by 300 examples. Small quarto $2.50

JERVIS.—Railroad Property:
A Treatise on the Construction and Management of Railways; designed to afford useful knowledge, in the popular style, to the holders of this class of property; as well as Railway Managers, Officers, and Agents. By JOHN B. JERVIS, late Civil Engineer of the Hudson River Railroad, Croton Aqueduct, etc. 12mo., cloth $2.00

KEENE.—A Hand-Book of Practical Gauging:
For the Use of Beginners, to which is added a Chapter on Distillation, describing the process in operation at the Custom-House for ascertaining the Strength of Wines. By JAMES B. KEENE, of H. M. Customs. 8vo. $1.25

KELLEY.—Speeches, Addresses, and Letters on Industrial and Financial Questions:
By HON. WILLIAM D. KELLEY, M. C. 544 pages, 8vo. . $2.50

KELLOGG.—A New Monetary System:
The only means of Securing the respective Rights of Labor and Property, and of Protecting the Public from Financial Revulsions. By EDWARD KELLOGG. Revised from his work on "Labor and other Capital." With numerous additions from his manuscript. Edited by MARY KELLOGG PUTNAM. Fifth edition. To which is added a Biographical Sketch of the Author. One volume, 12mo.
Paper cover $1.00
Bound in cloth 1.50

KEMLO.—Watch-Repairer's Hand-Book:
Being a Complete Guide to the Young Beginner, in Taking Apart, Putting Together, and Thoroughly Cleaning the English Lever and other Foreign Watches, and all American Watches. By F. KEMLO, Practical Watchmaker. With Illustrations. 12mo. . $1.25

KENTISH.—A Treatise on a Box of Instruments,
And the Slide Rule; with the Theory of Trigonometry and Logarithms, including Practical Geometry, Surveying, Measuring of Timber, Cask and Malt Gauging, Heights, and Distances. By THOMAS KENTISH. In one volume. 12mo. $1.25

KERL.—The Assayer's Manual:
An Abridged Treatise on the Docimastic Examination of Ores, and Furnace and other Artificial Products. By BRUNO KERL, Professor in the Royal School of Mines. Translated from the German by WILLIAM T. BRANNT. Second American edition, edited with Extensive Additions by F. LYNWOOD GARRISON, Member of the American Institute of Mining Engineers, etc. Illustrated by 87 engravings. 8vo. $3.00

KICK.—Flour Manufacture.
A Treatise on Milling Science and Practice. By FREDERICK KICK, Imperial Regierungsrath, Professor of Mechanical Technology in the Imperial German Polytechnic Institute, Prague. Translated from the second enlarged and revised edition with supplement by H. H. P. POWLES, Assoc. Memb. Institution of Civil Engineers. Illustrated with 28 Plates, and 167 Wood-cuts. 367 pages. 8vo. . $10.00

KINGZETT.—The History, Products, and Processes of the Alkali Trade:
Including the most Recent Improvements. By CHARLES THOMAS KINGZETT, Consulting Chemist. With 23 illustrations. 8vo. $2.50

KIRK.—The Founding of Metals:
A Practical Treatise on the Melting of Iron, with a Description of the Founding of Alloys; also, of all the Metals and Mineral Substances used in the Art of Founding. Collected from original sources. By EDWARD KIRK, Practical Foundryman and Chemist. Illustrated. Third edition. 8vo. $2.50

LANDRIN.—A Treatise on Steel:
Comprising its Theory, Metallurgy, Properties, Practical Working, and Use. By M. H. C. LANDRIN, JR., Civil Engineer. Translated from the French, with Notes, by A. A. FESQUET, Chemist and Engineer. With an Appendix on the Bessemer and the Martin Processes for Manufacturing Steel, from the Report of Abram S. Hewitt, United States Commissioner to the Universal Exposition, Paris, 1867. 12mo. $3.00

LANGBEIN.—A Complete Treatise on the Electro-Deposition of Metals:
Translated from the German, with Additions, by WM. T. BRANNT. 125 illustrations. 8vo. $4.00

LARDNER.—The Steam-Engine:
For the Use of Beginners. Illustrated. 12mo. 75

LEHNER.—The Manufacture of Ink:
Comprising the Raw Materials, and the Preparation of Writing, Copying and Hektograph Inks, Safety Inks, Ink Extracts and Powders, etc. Translated from the German of SIGMUND LEHNER, with additions by WILLIAM T. BRANNT. Illustrated. 12mo. $2.00

LARKIN.—The Practical Brass and Iron Founder's Guide:
A Concise Treatise on Brass Founding, Moulding, the Metals and their Alloys, etc.; to which are added Recent Improvements in the Manufacture of Iron, Steel by the Bessemer Process, etc., etc. By JAMES LARKIN, late Conductor of the Brass Foundry Department in Reany, Neafie & Co.'s Penn Works, Philadelphia. New edition, revised, with extensive additions. 12mo. $2.50

LEROUX.—A Practical Treatise on the Manufacture of Worsteds and Carded Yarns:
Comprising Practical Mechanics, with Rules and Calculations applied to Spinning; Sorting, Cleaning, and Scouring Wools; the English and French Methods of Combing, Drawing, and Spinning Worsteds, and Manufacturing Carded Yarns. Translated from the French of CHARLES LEROUX, Mechanical Engineer and Superintendent of a Spinning-Mill, by HORATIO PAINE, M. D., and A. A. FESQUET, Chemist and Engineer. Illustrated by twelve large Plates. To which is added an Appendix, containing Extracts from the Reports of the International Jury, and of the Artisans selected by the Committee appointed by the Council of the Society of Arts, London, on Woolen and Worsted Machinery and Fabrics, as exhibited in the Paris Universal Exposition, 1867. 8vo. $5.00

LEFFEL.—The Construction of Mill-Dams:
Comprising also the Building of Race and Reservoir Embankments and Head-Gates, the Measurement of Streams, Gauging of Water Supply, etc. By JAMES LEFFEL & Co. Illustrated by 58 engravings. 8vo. $2.50

LESLIE.—Complete Cookery:
Directions for Cookery in its Various Branches. By MISS LESLIE. Sixtieth thousand. Thoroughly revised, with the addition of New Receipts. 12mo. $1.50

LE VAN.—The Steam Engine and the Indicator:
Their Origin and Progressive Development; including the Most Recent Examples of Steam and Gas Motors, together with the Indicator, its Principles, its Utility, and its Application. By WILLIAM BARNET LE VAN. Illustrated by 205 Engravings, chiefly of Indicator-Cards. 469 pp. 8vo. $4.00

LIEBER.—Assayer's Guide:
Or, Practical Directions to Assayers, Miners, and Smelters, for the Tests and Assays, by Heat and by Wet Processes, for the Ores of all the principal Metals, of Gold and Silver Coins and Alloys, and of Coal, etc. By OSCAR M. LIEBER. Revised. 283 pp. 12mo. $1.50

Lockwood's Dictionary of Terms:
Used in the Practice of Mechanical Engineering, embracing those Current in the Drawing Office, Pattern Shop, Foundry, Fitting, Turning, Smith's and Boiler Shops, etc., etc., comprising upwards of Six Thousand Definitions. Edited by a Foreman Pattern Maker, author of "Pattern Making." 417 pp. 12mo. $3.00

LUKIN.—Amongst Machines:
Embracing Descriptions of the various Mechanical Appliances used in the Manufacture of Wood, Metal, and other Substances. 12mo. $1.75

LUKIN.—The Boy Engineers:
What They Did, and How They Did It. With 30 plates. 18mo. $1.75

LUKIN.—The Young Mechanic:
Practical Carpentry. Containing Directions for the Use of all kinds of Tools, and for Construction of Steam-Engines and Mechanical Models, including the Art of Turning in Wood and Metal. By JOHN LUKIN, Author of "The Lathe and Its Uses," etc. Illustrated. 12mo. $1.75

MAIN and BROWN.—Questions on Subjects Connected with the Marine Steam-Engine:
And Examination Papers; with Hints for their Solution. By THOMAS J. MAIN, Professor of Mathematics, Royal Naval College, and THOMAS BROWN, Chief Engineer, R. N. 12mo., cloth . $1.00

MAIN and BROWN.—The Indicator and Dynamometer:
With their Practical Applications to the Steam-Engine. By THOMAS J. MAIN, M. A. F. R., Ass't S. Professor Royal Naval College, Portsmouth, and THOMAS BROWN, Assoc. Inst. C. E., Chief Engineer R. N., attached to the R. N. College. Illustrated. 8vo. . $1.00

MAIN and BROWN.—The Marine Steam-Engine.
By THOMAS J. MAIN, F. R. Ass't S. Mathematical Professor at the Royal Naval College, Portsmouth, and THOMAS BROWN, Assoc. Inst. C. E., Chief Engineer R. N. Attached to the Royal Naval College. With numerous illustrations. 8vo. . .

MAKINS.—A Manual of Metallurgy:
By GEORGE HOGARTH MAKINS. 100 engravings. Second edition rewritten and much enlarged. 12mo., 592 pages . . $3.00

MARTIN.—Screw-Cutting Tables, for the Use of Mechanical Engineers:
Showing the Proper Arrangement of Wheels for Cutting the Threads of Screws of any Required Pitch; with a Table for Making the Universal Gas-Pipe Thread and Taps. By W. A. MARTIN, Engineer. 8vo. 50

MICHELL.—Mine Drainage:
Being a Complete and Practical Treatise on Direct-Acting Underground Steam Pumping Machinery. With a Description of a large number of the best known Engines, their General Utility and the Special Sphere of their Action, the Mode of their Application, and their Merits compared with other Pumping Machinery. By STEPHEN MICHELL. Illustrated by 137 engravings. 8vo., 277 pages . $6.00

MOLESWORTH.—Pocket-Book of Useful Formulæ and Memoranda for Civil and Mechanical Engineers.
By GUILFORD L. MOLESWORTH, Member of the Institution of Civil Engineers, Chief Resident Engineer of the Ceylon Railway. Full-bound in Pocket-book form $1.00

MOORE.—The Universal Assistant and the Complete Mechanic:
Containing over one million Industrial Facts, Calculations, Receipts, Processes, Trades Secrets, Rules, Business Forms, Legal Items, Etc., in every occupation, from the Household to the Manufactory. By R. MOORE. Illustrated by 500 Engravings. 12mo. . $2.50

MORRIS.—Easy Rules for the Measurement of Earthworks:
By means of the Prismoidal Formula. Illustrated with Numerous Wood-Cuts, Problems, and Examples, and concluded by an Extensive Table for finding the Solidity in cubic yards from Mean Areas. The whole being adapted for convenient use by Engineers, Surveyors, Contractors, and others needing Correct Measurements of Earthwork. By ELWOOD MORRIS, C. E. 8vo. $1.50

MORTON.—The System of Calculating Diameter, Circumference, Area, and Squaring the Circle:
Together with Interest and Miscellaneous Tables, and other information. By JAMES MORTON. Second Edition, enlarged, with the Metric System. 12mo. 50

NAPIER.—Manual of Electro-Metallurgy:
Including the Application of the Art to Manufacturing Processes. By JAMES NAPIER. Fourth American, from the Fourth London edition, revised and enlarged. Illustrated by engravings. 8vo.

NAPIER.—A System of Chemistry Applied to Dyeing.
By JAMES NAPIER, F. C. S. A New and Thoroughly Revised Edition. Completely brought up to the present state of the Science, including the Chemistry of Coal Tar Colors, by A. A. FESQUET, Chemist and Engineer. With an Appendix on Dyeing and Calico Printing, as shown at the Universal Exposition, Paris, 1867. Illustrated. 8vo. 422 pages $3.50

NEVILLE.—Hydraulic Tables, Coefficients, and Formulæ, for finding the Discharge of Water from Orifices, Notches, Weirs, Pipes, and Rivers:
Third Edition, with Additions, consisting of New Formulæ for the Discharge from Tidal and Flood Sluices and Siphons; general information on Rainfall, Catchment-Basins, Drainage, Sewerage, Water Supply for Towns and Mill Power. By JOHN NEVILLE, C. E. M. R. I. A.; Fellow of the Royal Geological Society of Ireland. Thick 12mo. $5.50

NEWBERY.—Gleanings from Ornamental Art of every style:
Drawn from Examples in the British, South Kensington, Indian, Crystal Palace, and other Museums, the Exhibitions of 1851 and 1862, and the best English and Foreign works. In a series of 100 exquisitely drawn Plates, containing many hundred examples. By ROBERT NEWBERY. 4to. $12.50

NICHOLLS.—The Theoretical and Practical Boiler-Maker and Engineer's Reference Book:
Containing a variety of Useful Information for Employers of Labor. Foremen and Working Boiler-Makers, Iron, Copper, and Tinsmiths

Draughtsmen, Engineers, the General Steam-using Public, and for the Use of Science Schools and Classes. By SAMUEL NICHOLLS. Illustrated by sixteen plates, 12mo. $2.50

NICHOLSON.—A Manual of the Art of Bookbinding:

Containing full instructions in the different Branches of Forwarding, Gilding, and Finishing. Also, the Art of Marbling Book-edges and Paper. By JAMES B. NICHOLSON. Illustrated. 12mo., cloth $2.25

NICOLLS.—The Railway Builder:

A Hand-Book for Estimating the Probable Cost of American Railway Construction and Equipment. By WILLIAM J. NICOLLS, Civil Engineer. Illustrated, full bound, pocket-book form . $2.00

NORMANDY.—The Commercial Handbook of Chemical Analysis:

Or Practical Instructions for the Determination of the Intrinsic or Commercial Value of Substances used in Manufactures, in Trades, and in the Arts. By A. NORMANDY. New Edition, Enlarged, and to a great extent rewritten. By HENRY M. NOAD, Ph.D., F.R.S., thick 12mo. $5.00

NORRIS.—A Handbook for Locomotive Engineers and Machinists:

Comprising the Proportions and Calculations for Constructing Locomotives; Manner of Setting Valves; Tables of Squares, Cubes, Areas, etc., etc. By SEPTIMUS NORRIS, M. E. New edition. Illustrated, 12mo. $1.50

NYSTROM.—A New Treatise on Elements of Mechanics:

Establishing Strict Precision in the Meaning of Dynamical Terms: accompanied with an Appendix on Duodenal Arithmetic and Metrology. By JOHN W. NYSTROM, C. E. Illustrated. 8vo. $2.00

NYSTROM.—On Technological Education and the Construction of Ships and Screw Propellers:

For Naval and Marine Engineers. By JOHN W. NYSTROM, late Acting Chief Engineer, U. S. N. Second edition, revised, with additional matter. Illustrated by seven engravings. 12mo. . $1.50

O'NEILL.—A Dictionary of Dyeing and Calico Printing:

Containing a brief account of all the Substances and Processes in use in the Art of Dyeing and Printing Textile Fabrics; with Practical Receipts and Scientific Information. By CHARLES O'NEILL, Analytical Chemist. To which is added an Essay on Coal Tar Colors and their application to Dyeing and Calico Printing. By A. A. FESQUET, Chemist and Engineer. With an appendix on Dyeing and Calico Printing, as shown at the Universal Exposition, Paris, 1867. 8vo., 491 pages $3.50

RTON.—Underground Treasures:

How and Where to Find Them. A Key for the Ready Determination of all the Useful Minerals within the United States. By JAMES ORTON, A.M., Late Professor of Natural History in Vassar College, N. Y.; Cor. Mem. of the Academy of Natural Sciences, Philadelphia, and of the Lyceum of Natural History, New York; author of the "Andes and the Amazon," etc. A New Edition, with Additions. Illustrated $1.50

OSBORN.—The Prospector's Field Book and Guide:
In the Search for and the Easy Determination of Ores and Other Useful Minerals. By Prof. H. S. OSBORN, LL. D., Author of "The Metallurgy of Iron and Steel;" "A Practical Manual of Minerals, Mines, and Mining." Illustrated by 44 Engravings. 12mo. $1.50

OSBORN.—A Practical Manual of Minerals, Mines and Mining:
Comprising the Physical Properties, Geologic Positions, Local Occurrence and Associations of the Useful Minerals; their Methods of Chemical Analysis and Assay: together with Various Systems of Excavating and Timbering, Brick and Masonry Work, during Driving, Lining, Bracing and other Operations, etc. By Prof. H. S. OSBORN, LL. D., Author of the "Metallurgy of Iron and Steel." Illustrated by 171 engravings from original drawings. 8vo. $4.50

OVERMAN.—The Manufacture of Steel:
Containing the Practice and Principles of Working and Making Steel. A Handbook for Blacksmiths and Workers in Steel and Iron, Wagon Makers, Die Sinkers, Cutlers, and Manufacturers of Files and Hardware, of Steel and Iron, and for Men of Science and Art. By FREDERICK OVERMAN, Mining Engineer, Author of the "Manufacture of Iron," etc. A new, enlarged, and revised Edition. By A. A. FESQUET, Chemist and Engineer. 12mo. . . . $1.50

OVERMAN.—The Moulder's and Founder's Pocket Guide:
A Treatise on Moulding and Founding in Green-sand, Dry-sand, Loam, and Cement; the Moulding of Machine Frames, Mill-gear, Hollow-ware, Ornaments, Trinkets, Bells, and Statues; Description of Moulds for Iron, Bronze, Brass, and other Metals; Plaster of Paris, Sulphur, Wax, etc.; the Construction of Melting Furnaces, the Melting and Founding of Metals; the Composition of Alloys and their Nature, etc., etc. By FREDERICK OVERMAN, M. E. A new Edition, to which is added a Supplement on Statuary and Ornamental Moulding, Ordnance, Malleable Iron Castings, etc. By A. A. FESQUET, Chemist and Engineer. Illustrated by 44 engravings. 12mo. . $2.00

PAINTER, GILDER, AND VARNISHER'S COMPANION:
Containing Rules and Regulations in everything relating to the Arts of Painting, Gilding, Varnishing, Glass-Staining, Graining, Marbling, Sign-Writing, Gilding on Glass, and Coach Painting and Varnishing; Tests for the Detection of Adulterations in Oils, Colors, etc.; and a Statement of the Diseases to which Painters are peculiarly liable, with the Simplest and Best Remedies. Sixteenth Edition. Revised, with an Appendix. Containing Colors and Coloring—Theoretical and Practical. Comprising descriptions of a great variety of Additional Pigments, their Qualities and Uses, to which are added, Dryers, and Modes and Operations of Painting, etc. Together with Chevreul's Principles of Harmony and Contrast of Colors. 12mo. Cloth $1.50

PALLETT.—The Miller's, Millwright's, and Engineer's Guide.
By HENRY PALLETT. Illustrated. 12mo. . . . $2.00

PERCY.—The Manufacture of Russian Sheet-Iron.
By JOHN PERCY, M. D., F. R. S., Lecturer on Metallurgy at the Royal School of Mines, and to The Advance Class of Artillery Officers at the Royal Artillery Institution, Woolwich; Author of "Metallurgy." With Illustrations. 8vo., paper . . 50 cts.

PERKINS.—Gas and Ventilation:
Practical Treatise on Gas and Ventilation. With Special Relation to Illuminating, Heating, and Cooking by Gas. Including Scientific Helps to Engineer-students and others. With Illustrated Diagrams. By E. E. PERKINS. 12mo., cloth $1.25

PERKINS AND STOWE.—A New Guide to the Sheet-iron and Boiler Plate Roller:
Containing a Series of Tables showing the Weight of Slabs and Piles to Produce Boiler Plates, and of the Weight of Piles and the Sizes of Bars to produce Sheet-iron; the Thickness of the Bar Gauge in decimals; the Weight per foot, and the Thickness on the Bar or Wire Gauge of the fractional parts of an inch; the Weight per sheet, and the Thickness on the Wire Gauge of Sheet-iron of various dimensions to weigh 112 lbs. per bundle; and the conversion of Short Weight into Long Weight, and Long Weight into Short. Estimated and collected by G. H. PERKINS and J. G. STOWE. $2.50

POWELL—CHANCE—HARRIS.—The Principles of Glass Making.
By HARRY J. POWELL, B. A. Together with Treatises on Crown and Sheet Glass; by HENRY CHANCE, M. A. And Plate Glass, by H. G. HARRIS, Asso. M. Inst. C. E. Illustrated 18mo. . $1.50

PROCTOR.—A Pocket-Book of Useful Tables and Formulæ for Marine Engineers:
By FRANK PROCTOR. Second Edition, Revised and Enlarged. Full-bound pocket-book form $1.50

REGNAULT.—Elements of Chemistry:
By M. V. REGNAULT. Translated from the French by T. FORREST BETTON, M. D., and edited, with Notes, by JAMES C. BOOTH, Melter and Refiner U. S. Mint, and WILLIAM L. FABER, Metallurgist and Mining Engineer. Illustrated by nearly 700 wood-engravings. Comprising nearly 1,500 pages. In two volumes, 8vo., cloth . $7.50

RICHARDS.—Aluminium:
Its History, Occurrence, Properties, Metallurgy and Applications, including its Alloys. By JOSEPH W. RICHARDS, A. C., Chemist and Practical Metallurgist, Member of the Deutsche Chemische Gesellschaft. Illustrated $5.00

RIFFAULT, VERGNAUD, and TOUSSAINT.—A Practical Treatise on the Manufacture of Colors for Painting:
Comprising the Origin, Definition, and Classification of Colors; the Treatment of the Raw Materials; the best Formulæ and the Newest Processes for the Preparation of every description of Pigment, and the Necessary Apparatus and Directions for its Use; Dryers; the Testing. Application, and Qualities of Paints, etc., etc. By MM. RIFFAULT, VERGNAUD, and TOUSSAINT. Revised and Edited by M.

F. MALEPEYRE. Translated from the French, by A. A. FESQUET, Chemist and Engineer. Illustrated by Eighty engravings. In one vol., 8vo., 659 pages $7.50

ROPER.—A Catechism of High-Pressure, or Non-Condensing Steam-Engines:

Including the Modelling, Constructing, and Management of Steam-Engines and Steam Boilers. With valuable illustrations. By STEPHEN ROPER, Engineer. Sixteenth edition, revised and enlarged. 18mo., tucks, gilt edge $2.00

ROPER.—Engineer's Handy-Book:

Containing a full Explanation of the Steam-Engine Indicator, and its Use and Advantages to Engineers and Steam Users. With Formulæ for Estimating the Power of all Classes of Steam-Engines; also, Facts, Figures, Questions, and Tables for Engineers who wish to qualify themselves for the United States Navy, the Revenue Service, the Mercantile Marine, or to take charge of the Better Class of Stationary Steam-Engines. Sixth edition. 16mo., 690 pages, tucks, gilt edge $3.50

ROPER.—Hand-Book of Land and Marine Engines:

Including the Modelling, Construction, Running, and Management of Land and Marine Engines and Boilers. With illustrations. By STEPHEN ROPER, Engineer. Sixth edition. 12mo., tucks, gilt edge. $3.50

ROPER.—Hand-Book of the Locomotive:

Including the Construction of Engines and Boilers, and the Construction, Management, and Running of Locomotives. By STEPHEN ROPER. Eleventh edition. 18mo., tucks, gilt edge . $2.50

ROPER.—Hand-Book of Modern Steam Fire-Engines.

With illustrations. By STEPHEN ROPER, Engineer. Fourth edition, 12mo., tucks, gilt edge $3.50

ROPER.—Questions and Answers for Engineers.

This little book contains all the Questions that Engineers will be asked when undergoing an Examination for the purpose of procuring Licenses, and they are so plain that any Engineer or Fireman of ordinary intelligence may commit them to memory in a short time. By STEPHEN ROPER, Engineer. Third edition $3.00

ROPER.—Use and Abuse of the Steam Boiler.

By STEPHEN ROPER, Engineer. Eighth edition, with illustrations. 18mo., tucks, gilt edge $2.00

ROSE.—The Complete Practical Machinist:

Embracing Lathe Work, Vise Work, Drills and Drilling, Taps and Dies, Hardening and Tempering, the Making and Use of Tools, Tool Grinding, Marking out Work, etc. By JOSHUA ROSE. Illustrated by 356 engravings. Thirteenth edition, thoroughly revised and in great part rewritten. In one vol., 12mo., 439 pages $2.50

ROSE.—Mechanical Drawing Self-Taught:

Comprising Instructions in the Selection and Preparation of Drawing Instruments, Elementary Instruction in Practical Mechanical Draw-

ing, together with Examples in Simple Geometry and Elementary Mechanism, including Screw Threads, Gear Wheels, Mechanical Motions, Engines and Boilers. By JOSHUA ROSE, M. E. Illustrated by 330 engravings. 8vo., 313 pages $4.00

ROSE.—The Slide-Valve Practically Explained:
Embracing simple and complete Practical Demonstrations of the operation of each element in a Slide-valve Movement, and illustrating the effects of Variations in their Proportions by examples carefully selected from the most recent and successful practice. By JOSHUA ROSE, M. E. Illustrated by 35 engravings . $1.00

ROSS.—The Blowpipe in Chemistry, Mineralogy and Geology:
Containing all Known Methods of Anhydrous Analysis, many Working Examples, and Instructions for Making Apparatus. By LIEUT.-COLONEL W. A. ROSS, R. A., F. G. S. With 120 Illustrations. 12mo. $2.00

SHAW.—Civil Architecture:
Being a Complete Theoretical and Practical System of Building, containing the Fundamental Principles of the Art. By EDWARD SHAW, Architect. To which is added a Treatise on Gothic Architecture, etc. By THOMAS W. SILLOWAY and GEORGE M. HARDING, Architects. The whole illustrated by 102 quarto plates finely engraved on copper. Eleventh edition. 4to. $10.00

SHUNK.—A Practical Treatise on Railway Curves and Location, for Young Engineers.
By W. F. SHUNK, C. E. 12mo. Full bound pocket-book form $2.00

SLATER.—The Manual of Colors and Dye Wares.
By J. W. SLATER. 12mo. $3.00

SLOAN.—American Houses:
A variety of Original Designs for Rural Buildings. Illustrated by 26 colored engravings, with descriptive references. By SAMUEL SLOAN, Architect. 8vo. $1.50

SLOAN.—Homestead Architecture:
Containing Forty Designs for Villas, Cottages, and Farm-houses, with Essays on Style, Construction, Landscape Gardening, Furniture, etc., etc. Illustrated by upwards of 200 engravings. By SAMUEL SLOAN, Architect. 8vo. $3.50

SLOANE.—Home Experiments in Science.
By T. O'CONOR SLOANE, E. M., A. M., Ph. D. Illustrated by 91 engravings. 12mo. $1.50

SMEATON.—Builder's Pocket-Companion:
Containing the Elements of Building, Surveying, and Architecture; with Practical Rules and Instructions connected with the subject. By A. C. SMEATON, Civil Engineer, etc. 12mo. . . . $1.50

SMITH.—A Manual of Political Economy.
By E. PESHINE SMITH. A New Edition, to which is added a full Index. 12mo. $1 25

SMITH.—Parks and Pleasure-Grounds:
Or Practical Notes on Country Residences, Villas, Public Parks, and Gardens. By CHARLES H. J. SMITH, Landscape Gardener and Garden Architect, etc., etc. 12mo. $2.00

SMITH.—The Dyer's Instructor:
Comprising Practical Instructions in the Art of Dyeing Silk, Cotton, Wool, and Worsted, and Woolen Goods; containing nearly 800 Receipts. To which is added a Treatise on the Art of Padding; and the Printing of Silk Warps, Skeins, and Handkerchiefs, and the various Mordants and Colors for the different styles of such work. By DAVID SMITH, Pattern Dyer. 12mo. $2.00

SMYTH.—A Rudimentary Treatise on Coal and Coal-Mining.
By WARRINGTON W. SMYTH, M. A., F. R. G., President R. G. S. of Cornwall. Fifth edition, revised and corrected. With numerous illustrations. 12mo. $1.75

SNIVELY.—Tables for Systematic Qualitative Chemical Analysis.
By JOHN H. SNIVELY, Phr. D. 8vo. $1.00

SNIVELY.—The Elements of Systematic Qualitative Chemical Analysis:
A Hand-book for Beginners. By JOHN H. SNIVELY, Phr. D. 16mo. $2.00

STOKES.—The Cabinet-Maker and Upholsterer's Companion:
Comprising the Art of Drawing, as applicable to Cabinet Work; Veneering, Inlaying, and Buhl-Work; the Art of Dyeing and Staining Wood, Ivory, Bone, Tortoise-Shell, etc. Directions for Lackering, Japanning, and Varnishing; to make French Polish, Glues, Cements, and Compositions; with numerous Receipts, useful to work men generally. By STOKES. Illustrated. A New Edition, with an Appendix upon French Polishing, Staining, Imitating, Varnishing, etc., etc. 12mo $1.25

STRENGTH AND OTHER PROPERTIES OF METALS:
Reports of Experiments on the Strength and other Properties of Metals for Cannon. With a Description of the Machines for Testing Metals, and of the Classification of Cannon in service. By Officers of the Ordnance Department, U. S. Army. By authority of the Secretary of War. Illustrated by 25 large steel plates. Quarto . $10.00

SULLIVAN.—Protection to Native Industry.
By Sir EDWARD SULLIVAN, Baronet, author of "Ten Chapters on Social Reforms." 8vo. $1.00

SULZ.—A Treatise on Beverages:
Or the Complete Practical Bottler. Full instructions for Laboratory Work, with Original Practical Recipes for all kinds of Carbonated Drinks, Mineral Waters, Flavorings, Extracts, Syrups, etc. By CHAS HERMAN SULZ, Technical Chemist and Practical Bottler Illustrated by 428 Engravings. 818 pp. 8vo. . . . $10.00

SYME.—Outlines of an Industrial Science.

By DAVID SYME. 12mo. $2.00

TABLES SHOWING THE WEIGHT OF ROUND, SQUARE, AND FLAT BAR IRON, STEEL, ETC.,

By Measurement. Cloth 63

TAYLOR.—Statistics of Coal:

Including Mineral Bituminous Substances employed in Arts and Manufactures; with their Geographical, Geological, and Commercial Distribution and Amount of Production and Consumption on the American Continent. With Incidental Statistics of the Iron Manufacture. By R. C. TAYLOR. Second edition, revised by S. S. HALDEMAN. Illustrated by five Maps and many wood engravings. 8vo., cloth $10.00

TEMPLETON.—The Practical Examinator on Steam and the Steam-Engine:

With Instructive References relative thereto, arranged for the Use of Engineers, Students, and others. By WILLIAM TEMPLETON, Engineer. 12mo. $1.00

THAUSING.—The Theory and Practice of the Preparation of Malt and the Fabrication of Beer:

With especial reference to the Vienna Process of Brewing. Elaborated from personal experience by JULIUS E. THAUSING, Professor at the School for Brewers, and at the Agricultural Institute, Mödling, near Vienna. Translated from the German by WILLIAM T. BRANNT. Thoroughly and elaborately edited, with much American matter, and according to the latest and most Scientific Practice, by A. SCHWARZ and DR. A. H. BAUER. Illustrated by 140 Engravings. 8vo., 815 pages $10.00

THOMAS.—The Modern Practice of Photography:

By R. W. THOMAS, F. C. S. 8vo. 75

THOMPSON.—Political Economy. With Especial Reference to the Industrial History of Nations:

By ROBERT E. THOMPSON, M. A., Professor of Social Science in the University of Pennsylvania. 12mo. $1.50

THOMSON.—Freight Charges Calculator:

By ANDREW THOMSON, Freight Agent. 24mo. . . . $1.25

TURNER'S (THE) COMPANION:

Containing Instructions in Concentric, Elliptic, and Eccentric Turning; also various Plates of Chucks, Tools, and Instruments; and Directions for using the Eccentric Cutter, Drill, Vertical Cutter, and Circular Rest; with Patterns and Instructions for working them 12mo. $1.25

TURNING: Specimens of Fancy Turning Executed on the Hand or Foot-Lathe:

With Geometric, Oval, and Eccentric Chucks, and Elliptical Cutting Frame. By an Amateur. Illustrated by 30 exquisite Photographs. 4to. $3.00

VAILE.—Galvanized-Iron Cornice-Worker's Manual:
Containing Instructions in Laying out the Different Mitres, and Making Patterns for all kinds of Plain and Circular Work. Also, Tables of Weights, Areas and Circumferences of Circles, and other Matter calculated to Benefit the Trade. By CHARLES A. VAILE. Illustrated by twenty-one plates. 4to. $5.00

VILLE.—On Artificial Manures:
Their Chemical Selection and Scientific Application to Agriculture. A series of Lectures given at the Experimental Farm at Vincennes, during 1867 and 1874–75. By M. GEORGES VILLE. Translated and Edited by WILLIAM CROOKES, F. R. S. Illustrated by thirty-one engravings. 8vo., 450 pages $6.00

VILLE.—The School of Chemical Manures:
Or, Elementary Principles in the Use of Fertilizing Agents. From the French of M. GEO. VILLE, by A. A. FESQUET, Chemist and Engineer. With Illustrations. 12mo. $1.25

VOGDES.—The Architect's and Builder's Pocket-Companion and Price-Book:
Consisting of a Short but Comprehensive Epitome of Decimals, Duodecimals, Geometry and Mensuration; with Tables of United States Measures, Sizes, Weights, Strengths, etc., of Iron, Wood, Stone, Brick, Cement and Concretes, Quantities of Materials in given Sizes and Dimensions of Wood, Brick and Stone; and full and complete Bills of Prices for Carpenter's Work and Painting; also, Rules for Computing and Valuing Brick and Brick Work, Stone Work, Painting, Plastering, with a Vocabulary of Technical Terms, etc. By FRANK W. VOGDES, Architect, Indianapolis, Ind. Enlarged, revised, and corrected. In one volume, 368 pages, full-bound, pocket-book form, gilt edges $2.00
Cloth 1.50

VAN CLEVE.—The English and American Mechanic:
Comprising a Collection of Over Three Thousand Receipts, Rules, and Tables, designed for the Use of every Mechanic and Manufacturer. By B. FRANK VAN CLEVE. Illustrated. 500 pp. 12mo. $2.00

WAHNSCHAFFE.—A Guide to the Scientific Examination of Soils:
Comprising Select Methods of Mechanical and Chemical Analysis and Physical Investigation. Translated from the German of Dr. F. WAHNSCHAFFE. With additions by WILLIAM T. BRANNT. Illustrated by 25 engravings. 12mo. 177 pages $1.50

WALL.—Practical Graining:
With Descriptions of Colors Employed and Tools Used. Illustrated by 47 Colored Plates, Representing the Various Woods Used in Interior Finishing. By WILLIAM E. WALL. 8vo. . $2.50

WALTON.—Coal-Mining Described and Illustrated:
By THOMAS H. WALTON, Mining Engineer. Illustrated by 24 large and elaborate Plates, after Actual Workings and Apparatus. $5.00

WARE.—The Sugar Beet.

Including a History of the Beet Sugar Industry in Europe, Varieties of the Sugar Beet, Examination, Soils, Tillage, Seeds and Sowing, Yield and Cost of Cultivation, Harvesting, Transportation, Conservation, Feeding Qualities of the Beet and of the Pulp, etc. By LEWIS S. WARE, C. E., M. E. Illustrated by ninety engravings. 8vo. $4.00

WARN.—The Sheet-Metal Worker's Instructor:

For Zinc, Sheet-Iron, Copper, and Tin-Plate Workers, etc. Containing a selection of Geometrical Problems; also, Practical and Simple Rules for Describing the various Patterns required in the different branches of the above Trades. By REUBEN H. WARN, Practical Tin-Plate Worker. To which is added an Appendix, containing Instructions for Boiler-Making, Mensuration of Surfaces and Solids, Rules for Calculating the Weights of different Figures of Iron and Steel, Tables of the Weights of Iron, Steel, etc. Illustrated by thirty-two Plates and thirty-seven Wood Engravings. 8vo. . $3.00

WARNER.—New Theorems, Tables, and Diagrams, for the Computation of Earth-work:

Designed for the use of Engineers in Preliminary and Final Estimates, of Students in Engineering, and of Contractors and other non-professional Computers. In two parts, with an Appendix. Part I. A Practical Treatise; Part II. A Theoretical Treatise, and the Appendix. Containing Notes to the Rules and Examples of Part I.; Explanations of the Construction of Scales, Tables, and Diagrams, and a Treatise upon Equivalent Square Bases and Equivalent Level Heights. The whole illustrated by numerous original engravings, comprising explanatory cuts for Definitions and Problems, Stereometric Scales and Diagrams, and a series of Lithographic Drawings from Models; Showing all the Combinations of Solid Forms which occur in Railroad Excavations and Embankments. By JOHN WARNER, A. M., Mining and Mechanical Engineer. Illustrated by 14 Plates. A new, revised and improved edition. 8vo. $4.00

WATSON.—A Manual of the Hand-Lathe:

Comprising Concise Directions for Working Metals of all kinds, Ivory, Bone and Precious Woods; Dyeing, Coloring, and French Polishing; Inlaying by Veneers, and various methods practised to produce Elaborate work with Dispatch, and at Small Expense. By EGBERT P. WATSON, Author of "The Modern Practice of American Machinists and Engineers." Illustrated by 78 engravings. $1.50

WATSON.—The Modern Practice of American Machinists and Engineers:

Including the Construction, Application, and Use of Drills, Lathe Tools, Cutters for Boring Cylinders, and Hollow-work generally, with the most Economical Speed for the same; the Results verified by Actual Practice at the Lathe, the Vise, and on the Floor. Together

with Workshop Management, Economy of Manufacture, the Steam-Engine, Boilers, Gears, Belting, etc., etc. By EGBERT P. WATSON. Illustrated by eighty-six engravings. 12mo. $2.50

WATSON.—The Theory and Practice of the Art of Weaving by Hand and Power:
With Calculations and Tables for the Use of those connected with the Trade. By JOHN WATSON, Manufacturer and Practical Machine-Maker. Illustrated by large Drawings of the best Power Looms. 8vo. $6.00

WATT.—The Art of Soap Making:
A Practical Hand-book of the Manufacture of Hard and Soft Soaps, Toilet Soaps, etc., including many New Processes, and a Chapter on the Recovery of Glycerine from Waste Leys. By ALEXANDER WATT. Ill. 12mo. $3.00

WEATHERLY.—Treatise on the Art of Boiling Sugar, Crystallizing, Lozenge-making, Comfits, Gum Goods,
And other processes for Confectionery, etc., in which are explained, in an easy and familiar manner, the various Methods of Manufacturing every Description of Raw and Refined Sugar Goods, as sold by Confectioners and others. 12mo. $1.50

WIGHTWICK.—Hints to Young Architects:
Comprising Advice to those who, while yet at school, are destined to the Profession; to such as, having passed their pupilage, are about to travel; and to those who, having completed their education, are about to practise. Together with a Model Specification involving a great variety of instructive and suggestive matter. By GEORGE WIGHTWICK, Architect. A new edition, revised and considerably enlarged; comprising Treatises on the Principles of Construction and Design. By G. HUSKISSON GUILLAUME, Architect. Numerous Illustrations. One vol. 12mo. $2.00

WILL.—Tables of Qualitative Chemical Analysis.
With an Introductory Chapter on the Course of Analysis. By Professor HEINRICH WILL, of Giessen, Germany. Third American, from the eleventh German edition. Edited by CHARLES F. HIMES, Ph. D., Professor of Natural Science, Dickinson College, Carlisle, Pa. 8vo. $1.50

WILLIAMS.—On Heat and Steam:
Embracing New Views of Vaporization, Condensation, and Explosion. By CHARLES WYE WILLIAMS, A. I. C. E. Illustrated 8vo. $3 50

WILSON.—A Treatise on Steam Boilers:
Their Strength, Construction, and Economical Working. By ROBERT WILSON. Illustrated 12mo. $2.50

WILSON.—First Principles of Political Economy:
With Reference to Statesmanship and the Progress of Civilization. By Professor W. D. WILSON, of the Cornell University. A new and revised edition. 12mo. $1.50

WOHLER.—A Hand-Book of Mineral Analysis:

By F. WÖHLER, Professor of Chemistry in the University of Göttingen. Edited by HENRY B. NASON, Professor of Chemistry in the Renssalaer Polytechnic Institute, Troy, New York. Illustrated. 12mo. $3.00

WORSSAM.—On Mechanical Saws:

From the Transactions of the Society of Engineers, 1869. By S. W. WORSSAM, JR. Illustrated by eighteen large plates. 8vo. $2.50

RECENT ADDITIONS.

ANDERSON.—The Prospector's Hand-Book:

A Guide for the Prospector and Traveler in Search of Metal Bearing or other Valuable Minerals. By J. W. ANDERSON. 52 Illustrations. 12mo. $1.50

BRANNT—The Practical Scourer and Garment Dyer:

Comprising Dry or Chemical Cleaning; the Art of Removing Stains; Fine Washing; Bleaching and Dyeing of Straw Hats, Gloves, and Feathers of all kinds; Dyeing of Worn Clothes of all fabrics, including Mixed Goods, by One Dip; and the Manufacture of Soaps and Fluids for Cleansing Purposes. Edited by WILLIAM T. BRANNT, Editor of "The Techno-Chemical Receipt Book." Illustrated. 203 pages. 12mo. $2.00

BRANNT.—The Metallic Alloys:

A Practical Guide for the Manufacture of all kinds of Alloys, Amalgams and Solders used by Metal Workers, especially by Bell Founders, Bronze Workers, Tinsmiths, Gold and Silver Workers, Dentists, etc., etc., as well as their Chemical and Physical Properties. Edited chiefly from the German of A. Krupp and Andreas Wildberger, with additions by WM. T. BRANNT. Illustrated. 12mo. $3.00

BRANNT.—A Practical Treatise on the Manufacture of Vinegar and Acetates, Cider, and Fruit-Wines:

Preservation of Fruits and Vegetables by Canning and Evaporation; Preparation of Fruit-Butters, Jellies, Marmalades, Catchups, Pickles, Mustards, etc. Edited from various sources. By WILLIAM T. BRANNT. Illustrated by 79 Engravings. 479 pp. 8vo. $5.00

BRANNT.—The Metal Worker's Handy-Book of Receipts and Processes:

Being a Collection of Chemical Formulas and Practical Manipulations for the working of all Metals; including the Decoration and Beautifying of Articles Manufactured therefrom, as well as their Preservation. Edited from various sources. By WILLIAM T. BRANNT. Illustrated. 12mo. $2.50

DEITE.—A Practical Treatise on the Manufacture of Perfumery:
Comprising directions for making all kinds of Perfumes, Sachet Powders, Fumigating Materials, Dentifrices, Cosmetics, etc., with a full account of the Volatile Oils, Balsams, Resins, and other Natural and Artificial Perfume-substances, including the Manufacture of Fruit Ethers, and tests of their purity. By Dr. C. DEITE, assisted by L. BORCHERT, F. EICHBAUM, E. KUGLER, H. TOEFFNER, and other experts. From the German, by WM. T. BRANNT. 28 Engravings. 358 pages. 8vo. $3.00

EDWARDS.—American Marine Engineer, Theoretical and Practical:
With Examples of the latest and most approved American Practice. By EMORY EDWARDS. 85 illustrations. 12mo. . . $2.50

EDWARDS.—600 Examination Questions and Answers:
For Engineers and Firemen (Land and Marine) who desire to obtain a United States Government or State License. Pocket-book form, gilt edge $1.50

POSSELT.—Technology of Textile Design:
Being a Practical Treatise on the Construction and Application of Weaves for all Textile Fabrics, with minute reference to the latest Inventions for Weaving. Containing also an Appendix, showing the Analysis and giving the Calculations necessary for the Manufacture of the various Textile Fabrics. By E. A. POSSELT, Head Master Textile Department, Pennsylvania Museum and School of Industrial Art, Philadelphia, with over 1000 illustrations. 292 pages. 4to. $5.00

POSSELT.—The Jacquard Machine Analysed and Explained:
With an Appendix on the Preparation of Jacquard Cards, and Practical Hints to Learners of Jacquard Designing. By E. A. POSSELT. With 230 illustrations and numerous diagrams. 127 pp. 4to. $3.00

POSSELT.—The Structure of Fibres, Yarns and Fabrics:
Being a Practical Treatise for the Use of all Persons Employed in the Manufacture of Textile Fabrics, containing a Description of the Growth and Manipulation of Cotton, Wool, Worsted, Silk, Flax, Jute, Ramie, China Grass and Hemp, and Dealing with all Manufacturers' Calculations for Every Class of Material, also Giving Minute Details for the Structure of all kinds of Textile Fabrics, and an Appendix of Arithmetic, specially adapted for Textile Purposes. By E. A. POSSELT. Over 400 Illustrations. quarto. . $10.00

RICH.—Artistic Horse-Shoeing:
A Practical and Scientific Treatise, giving Improved Methods of Shoeing, with Special Directions for Shaping Shoes to Cure Different Diseases of the Foot, and for the Correction of Faulty Action in Trotters. By GEORGE E. RICH. 62 Illustrations. 153 pages. 12mo. $1.00

RICHARDSON.—Practical Blacksmithing:

A Collection of Articles Contributed at Different Times by Skilled Workmen to the columns of "The Blacksmith and Wheelwright," and Covering nearly the Whole Range of Blacksmithing, from the Simplest Job of Work to some of the Most Complex Forgings. Compiled and Edited by M. T. RICHARDSON.

Vol. I. 210 Illustrations. 224 pages. 12mo. . . $1.00
Vol. II. 230 Illustrations. 262 pages. 12mo. . . $1.00
Vol. III. 390 Illustrations. 307 pages. 12mo. . . $1 00
Vol. IV. 226 Illustrations. 276 pages. 12mo. . . $1.00

RICHARDSON.—The Practical Horseshoer:

Being a Collection of Articles on Horseshoeing in all its Branches which have appeared from time to time in the columns of "The Blacksmith and Wheelwright," etc. Compiled and edited by M. T. RICHARDSON. 174 illustrations. $1.00

ROPER.—Instructions and Suggestions for Engineers and Firemen:

By STEPHEN ROPER, Engineer. 18mo. Morocco . $2.00

ROPER.—The Steam Boiler: Its Care and Management:

By STEPHEN ROPER, Engineer. 12mo., tuck, gilt edges. $2.00

ROPER.—The Young Engineer's Own Book:

Containing an Explanation of the Principle and Theories on which the Steam Engine as a Prime Mover is Based. By STEPHEN ROPER, Engineer. 160 illustrations, 363 pages. 18mo., tuck . $3.00

ROSE.—Modern Steam-Engines:

An Elementary Treatise upon the Steam-Engine, written in Plain language; for Use in the Workshop as well as in the Drawing Office. Giving Full Explanations of the Construction of Modern Steam-Engines: Including Diagrams showing their Actual operation. Together with Complete but Simple Explanations of the operations of Various Kinds of Valves, Valve Motions, and Link Motions, etc., thereby Enabling the Ordinary Engineer to clearly Understand the Principles Involved in their Construction and Use, and to Plot out their Movements upon the Drawing Board. By JOSHUA ROSE, M. E. Illustrated by 422 engravings. Revised. 358 pp. . . $6.00

ROSE.—Steam Boilers:

A Practical Treatise on Boiler Construction and Examination, for the Use of Practical Boiler Makers, Boiler Users, and Inspectors; and embracing in plain figures all the calculations necessary in Designing or Classifying Steam Boilers. By JOSHUA ROSE, M. E. Illustrated by 73 engravings. 250 pages. 8vo. $2.50

SCHRIBER.—The Complete Carriage and Wagon Painter:

A Concise Compendium of the Art of Painting Carriages, Wagons, and Sleighs, embracing Full Directions in all the Various Branches, including Lettering, Scrolling, Ornamenting, Striping, Varnishing, and Coloring, with numerous Recipes for Mixing Colors. 73 Illustrations. 177 pp. 12mo. $1.00

$\frac{\text{ike}}{\text{p.te}}$ c